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LEOPOLD-MADDOCK EQUATIONS FOR NORTH SASKATCHEWAN RIVER WATER QUALITY STUDY EDMONTON-SASKATCHEWAN BORDER

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1.0 INTRODUCTION

1.1 Background

Due to increased environmental awareness, the effects of effluent discharge on the water quality of rivers has become an important concern. An area of particular concern is the reach of the North Saskatchewan River from the City of Edmonton to the Saskatchewan border. In order to assess the impact of existing effluent discharges and determine the impact of future effluent discharges, the Planning Division of Alberta Environment uses several water quality models. These models rely on a description of river hydraulics in the form of Leopold-Maddocks equations. The Leopold-Maddock equations are power or exponential equations and allow a direct method of relating depth, top width, and velocity to a varying discharge.

As the effect of effluent discharge in northern Alberta rivers is greatest during the winter months, the determination of Leopold-Maddocks equations under ice covered conditions was also required. However, little information is available on this subject.

Due to this lack of available information, the River Engineering Branch was requested by the Planning Division to conduct open water and ice cover surveys along the North Saskatchewan River from Edmonton to the Saskatchewan border. Using this data, a determination of Leopold-Maddock equations for ice covered and open water conditions would be derived.

1.2 Objectives

The objectives identified by the Planning Branch were to

1) Perform field surveys necessary to determine the geometric characteristics of nine reaches along the North Saskatchewan River.

2) Perform field surveys to determine hydraulic characteristics under ice cover conditions.

3) Perform field surveys to determine hydraulic characteristics under open water conditions.

4) Using various hydraulic programs, determine Leopold-Maddocks equations for nine reaches under both open water and ice cover conditions.

2.0 FIELD INVESTIGATIONS

2.1 Study Reaches

To provide continuity with the Planning Divisions water quality model, the 336.3 kilometre length of river was divided into nine reaches. These reaches are shown in Figure 1 and start with Reach I at the Saskatchewan border and continue to Reach A at the E.L. Smith water treatment plant in Edmonton. Reach A was subdivided into three sub-reaches A1, A2, A3 due to variations of partial and full ice cover.

2.2 Methodology

In order to provide a representative geometric representation of each reach, several river cross-sections must be surveyed. A review of available data bases found that river surveys had been completed by the Alberta Research Council in the late 1960's and early 1970's. However, as this information was relatively out of date and surveyed to assumed datum with no permanent benchmark reference, this data base was abandoned. An examination of River Engineering Branch databases found surveyed geodetic cross-sections extending from the Vinca Bridge at Redwater to the E.L. Smith water treatment plant located upstream of Edmonton. These cross-sections had been surveyed in 1986 and 1973 and had permanent benchmark references and locations. However, no data was found for the area from the Vinca Bridge to the Saskatchewan border. In order to develop a database for this area, cross section surveys at forty sites were required. These sites are shown in Figure 2.

To provide the required data base, field work was necessary to provide cross-sectional, and hydraulic information under both open water and ice covered conditions. Due to the large scope of the field work and the limited manpower available, the field work was divided into two parts, with Hamilton Olsen Surveys assigned to the gathering of relevant hydraulic and cross-sectional information under ice covered conditions and the Survey Branch (Technical Services Division) of Alberta Environment assigned to gather hydraulic data under open water conditions, perform cross-section surveys, and tie the cross-sections to geodetic elevation.

2.2.1 Ice Covered Conditions

Staff members of Hamilton Olsen Surveys and the River Engineering Branch completed an extensive series of field measurements during the month of January 22, 1990 and February 22, 1990. These measurements included a minimum of ten ice thickness, water level, frazil ice, channel bed, turbidity, and relative velocity measurements at each of the forty cross-sections that had a complete ice cover. As well, the location of shear walls and ice pack conditions were also noted. The range of work extended from Fort Saskatchewan to the Saskatchewan border.

In areas of partial ice cover extending from Fort Saskatchewan to the E.L. Smith water treatment plant, River Engineering Branch staff completed water level surveys and some ice thickness measurements. Due to safety concerns, measurements were somewhat limited.

Discharges during this time period ranged from 95 to 245 cms. These flows are typical of discharges during the winter months.

2.2.2. Open Water Conditions

Staff members of the Survey Branch completed the geodetic tie in of the forty new cross-sections over the winter months and were able to complete the sounding of the cross-sections by August,1990. The resulting cross-sections are shown in Figure 3, sheets 1 to 51.

At the completion of the sounding, a water level profile under open water conditions was completed from Edmonton the Saskatchewan border on August 14 and 15, 1991. The discharge during this time period was 210 cms.

3.0 HYDRAULIC ANALYSIS

3.1 Ice Covered Conditions

3.1.1 Methodology

To determine the hydraulic parameters for the various reaches, the mathematical model HEC-2, a computer program developed by the U.S. Army Corps of Engineers Hydrologic Engineering Centre was used.

This program requires the input of geometric (channel and overbank cross sections), and hydraulic (discharge, ice thickness, recorded water levels, roughness coefficients) data, which are used to calculate the water surface profile. The geometric portion of study reaches was well defined by the surveys completed in 1990, 1986, and 1973. Using this surveyed data base, the geometric data was assembled. The addition of the hydraulic data describing the ice thickness, shear walls, effective flow areas, discharges and recorded water levels completed the HEC2 database construction.

Using the completed database, the model was calibrated to recorded water levels. Calibration discharges were 107cms for Reach A1, 120 for Reach A2, 95 for Reaches A3 and B-A, 175 cms for Reach C-B, 153 cms for Reach D-C, 245 cms for Reach E-D, 110 cms for Reach F-E, 108 cms for Reach I-F. Due to the inaccuracies inherent in calibrating water levels under ice covered conditions, a calibration margin of +/- 0.2 metres was allowed. Areas of frazil ice, high turbidity with no velocity, and shear wall bed contacts were considered as ineffective flow areas. Typical ice thicknesses ranged from 0.7 to 1.0 metres. Mannings "n" for the channel bed and ice cover averaged 0.035 and 0.05 respectively. However at several sites, Manning's roughness reached as high as 0.080 to account for the downstream effects of severe ice jam conditions.

Once the models had been calibrated to actual field measurements, the models were run for a series of multiple discharges ranging from 50 to 500 cms in 10 to 100 cms increments. As the calibration discharges of 95 to 245 cms were in the midpoint of this range, some degree of confidence can be placed on the hydraulic parameters calculated by the multiple discharge runs. It should be noted that: "TransAlta Utilities attempts to maintain somewhere between 90 and 110 cms flow at Edmonton during the winter months. Estimated 1:10 year seven day low flows for Edmonton are around 50 cms." (personal communication with A. De Boer, P.Eng. Hydrology Branch, May 1990). The hydraulic parameters calculated at discharges above 300 cms. may be somewhat suspect. Field surveys of hydraulic parameters during higher flow periods would be necessary to verify the calculated hydraulic parameters.

Following the multiple discharge runs, the calculated hydraulic parameters for each cross section were divided into groups from reaches A to I. The required hydraulic parameters necessary to calculate the Leopold Maddock equations were effective flow area under ice sheet, topwidth, channel velocity, and mean depth.

3.2 Open Water Conditions

3.2.1. Methodology

Using the open water conditions database, calibration to recorded water levels under open water conditions began. Due to the distance between cross-sections, critical flow areas during low flows, and the need for intermediate cross sections, calibration was quite difficult. To avoid using unreasonable bed roughnesses, the CHPROP program was used instead. This program uses the hydraulic parameters on a cross section by cross section basis using surveyed water levels, water slope, Mannings roughness, discharge, and geometric cross sections. The open water model was calibrated to a +/- 0.1 metre margin. Calibration discharges were as follows, 230 cms for Reaches D to I, 190 cms for Reaches B to D, 250 cms for Reaches A2 to B, and 195 cms for Reaches A1 to A2.

Once the calibration had been completed, a series of multiple discharge runs ranging from 50 to 500 cms were completed. Following the multiple discharge runs, the computed hydraulic parameters of topwidth, channel velocity, area, depth, and mean depth were divided into groups from Reaches A to I.

4.0 LEOPOLD MADDOCKS ANALYSIS

4.1 Methodology

4.1.1. Ice Covered Conditions

Following the calibration of the HEC2 and CHPROP programs and the multiple discharge runs, the resulting hydraulic parameter datasets for each reach were imported to the statistical charting program Charisma. Each subset of velocity, mean depth, and topwidth for the fourteen varying discharges for each reach was plotted against each other to determine if any obvious anomalies occurred. In reach G, the hydraulic parameters for one cross sections were deemed not representative of the study reach and removed from the analysis. Once the unrepresentative cross sections data sets had been removed, a multiple regression of the data sets for each reach was begun. The pertinent Leopold-Maddock equation and correlation was also calculated. The resulting graphs and equations for each reach are shown in Figures 4a to 12b. The resulting Leopold-Maddock equations for each reach and hydraulic parameter are summarized in Table 1.

TABLE 1

LEOPOLD-MADDOCK'S EQUATIONS FOR NORTH SASKATCHEWAN RIVER REACHES A-I

REACH	TOP WIDTH (TW)		DEPTH (D)		VELOCITY (V)	
	ICE CONDITIONS	OPEN CONDITIONS	ICE CONDITIONS	OPEN CONDITIONS	ICE CONDITIONS	OPEN CONDITIONS
A.1	169.03Q^0.02		0.15Q^0.40		0.04Q^0.59	
A.2*	99.71Q^0.11		0.16Q^0.42		0.06Q^0.47	
A.3	119.62Q^0.07		0.08Q^0.63		0.11Q^0.30	
A		114.75Q^0.09		0.13Q^0.48		0.07Q^0.43
B	125.94Q^0.05	136.65Q^0.07	0.12Q^0.55	0.09Q^0.56	0.07Q^0.40	0.08Q^0.37
C	160.21Q^0.06	158.60Q^0.06	0.02Q^0.81	0.07Q^0.56	0.28Q^0.13	0.10Q^0.38
D	145.34Q^0.04	99.25Q^0.13	0.07Q^0.61	0.08Q^0.53	0.10Q^0.34	0.12Q^0.34
E	159.77Q^0.03	147.27Q^0.07	0.07Q^0.63	0.08Q^0.53	0.09Q^0.35	0.09Q^0.40
F	169.67Q^0.04	130.29Q^0.08	0.07Q^0.61	0.09Q^0.50	0.08Q^0.36	0.09Q^0.42
G	174.43Q^0.07	99.24Q^0.15	0.02Q^0.91	0.09Q^0.50	0.34Q^0.02	0.11Q^0.35
H	155.29Q^0.04	117.28Q^0.11	0.09Q^0.61	0.09Q^0.53	0.07Q^0.35	0.09Q^0.36
I	196.69Q^0.06	97.88Q^0.18	0.10Q^0.54	0.11Q^0.49	0.05Q^0.40	0.10Q^0.33

Note: $Tw = dQ^{b}$
$D = cQ^{d}$
$V = eQ^{f}$

where Q = discharge (m^3/sec)
Tw = Top Width (m)
D = Mean Depth (m)
V = mean velocity (m^3/sec)
b-f=coefficiencts determined by regression analysis

* Partial Ice Cover

TABLE 2

CORRELLATION COEFFICIENTS FROM REGRESSION ANALYSIS

REACH	TOP WIDTH (TW)		DEPTH (D)		VELOCITY (V)	
	ICE CONDITIONS	OPEN CONDITIONS	ICE CONDITIONS	OPEN CONDITIONS	ICE CONDITIONS	OPEN CONDITIONS
A.1	0.40		0.65		0.76	
A.2*	0.43		0.87		0.86	
A.3	0.13		0.86		0.60	
A		0.42		0.71		0.73
B	0.09	0.45	0.68	0.89	0.84	0.88
C	0.21	0.20	0.80	0.69	0.23	0.77
D	0.10	0.31	0.75	0.78	0.69	0.85
E	*0.07	0.26	0.80	0.88	0.79	0.89
F	0.11	0.19	0.71	0.60	0.75	0.78
G	0.07	0.35	0.91	0.84	0.14	+0.95
H	0.17	0.35	0.93	0.75	0.80	0.76
I	0.24	0.59	0.85	0.87	0.94	0.87
AVERAGE	0.19	0.35	0.77	0.78	0.74	0.83

* Minimum
+ Maximum

5.0 ANALYSIS OF RESULTS

5.1 Correlation Coefficients

As can be seen from Table 2, correlation coefficients ranged from a low of 0.07 to a maximum of 0.95 with topwidth having the lowest correlation, and velocity the highest. This wide variation in correlation is due in part to the characteristic being measured.

Under open water conditions topwidth may change dramatically with a small rise or fall in stage particularly if discharge is below bankfull capacity. During extremely low discharges topwidth will increase at a much faster rate than a corresponding discharge. This increased rate of topwidth will continue until the flow is constricted by the existing primary banks.
Under ice covered conditions, topwidth is restricted by the shear walls of ice which were created during freeze up. As such, the topwidth equations will represent a constant width with a corresponding horizontal equation in all but the most minor discharges. From year to year, shear wall locations, frazil pockets, and ice thicknessess will vary, resulting in a variation in topwidth, depth, and velocity at various cross sections.

The resulting equations and in particular the equation defining topwidth should therefore be used with the realization that they are at best an approximation of the natural hydraulic characteristics and do not account for the diverse nature of the flow components of the channel. Correlations in the low range indicate at best a general trend.

Reference to the WQRRS manual indicates that a HEC2 data base could be incorporated into the WQRRS data base. As much of the North Saskatchewan River is described in terms of a HEC2 data base, the provision of a calibrated HEC2 data base would be relatively simple. The incorporation of the HEC2 data base with the WQRRS model would provide a much more representative model then the Leopold-Maddock equations.

5.2 Comparison With Alberta Research Council Time Of Travel Study

As part of the North Saskatchewan Water Quality Study, the Alberta Research Council was requested by the Planning Division to conduct winter tracer dye studies along the North Saskatchewan River. These studies were conducted from mid to late winter during the winter of 1989/90. Discharges during this test period ranged from 108 to 153 cms. The mean water velocities calculated from the time of travel of the peak dye concentration was 0.65 m/s in the open water reaches A1 to A3 between Edmonton and Fort Saskatchewan, 0.55 m/s in the ice covered reaches B,C,and D, between Fort Saskatchewan and Shandro and 0.49 m/s in the ice covered Reaches D to I from Shandro to the Saskatchewan border. A comparison of these measured under ice velocities with River Engineering computed velocities is shown in Table 3.

5.2 Comparison with Alberta Research Council Time of Travel Study (cont.)

As can be seen, the velocities computed by the River Engineering Branch are slightly less than those measured by the Alberta Research Council. This difference is attributed to a reduction in ice roughness due to thermal erosion of the bottom of the ice sheet. Much of the calibration levels used by the River Engineering Branch were surveyed during early to mid winter when the bottom ice cover was still fairly rough. The time of travel measurements taken by the Alberta Research Council were completed during late winter in mid March. This one to two month change in calibration dates may explain the reduced velocities during early winter. Further field studies would be required to measure the effects of thermal erosion of the bottom of ice sheets on the velocities and depths of ice covered rivers.

TABLE 3

Comparison of Measured and Computed Velocities

During Ice Covered Conditions

Reach	Mean Discharge (cms)	A.R.C. Velocity (m/s)	R.E.B. Velocity (m/s)
Edmonton-Ft.Sask Reaches A1-A3	129	0.65	0.58
Ft. Sask- Shandro Reaches B,C,D	125	0.55	0.51
Shandro- Border Reaches E,F,G,H,I	131	0.49	0.41

6.0 RECOMMENDATIONS FOR FURTHER WATER QUALITY STUDIES

6.1 Slope

This particular study contains cross section that are spaced fairly far apart. Between cross sections the slope generated may not represent the true slope at the cross sections selected. Therefore a local slope should be determined.

Survey for water slope upstream and downstream of the cross section to get local slope.

A general rule of thumb for survey purposes is to space surveyed point one or two river widths upstream and downstream of the cross section.

6.2 Roughness

Although an overall roughness for a reach can be arrived at by experience with similar rivers or reaches or previous studies there may be exceptions to the overall roughness at a particular cross section.

Surface ice morphology is a rough indicator of the roughness of the underside therefore a brief description of the morphology should continue to be a part of the survey notes. The appearance of the ice surface may be described as very smooth...rough...chaotic with the appropriate intermediate descriptors.

Photographs can be very useful to complement survey descriptions. However during bright light conditions the contrast on snow covered rivers may not be all that useful for recording surface morphology.

Another possible method would be to use a simple probe to drag along the underside of the ice and channel bed to approximate the degree of roughness. The probe may be as simple as a rigid wire attached to the end of a stiff dowel and bent into a semi-circle to "feel" the underside of the solid and frazil ice surfaces.

6.3 Effective Flow Areas

Ineffective flow areas can roughly be approximated by noting the presence of shear lines, relative water velocities and turbidity. Shear line location could be noted under surface morphology. Relative water velocity and turbidity and be subjectively described e.g. velocity may be noted as nil...strong...very strong, and, turbidity noted as very dirty...dirty...clear. Nil and very dirty observations at a sample site indicate an ineffective flow zone.

STUDY REACHES

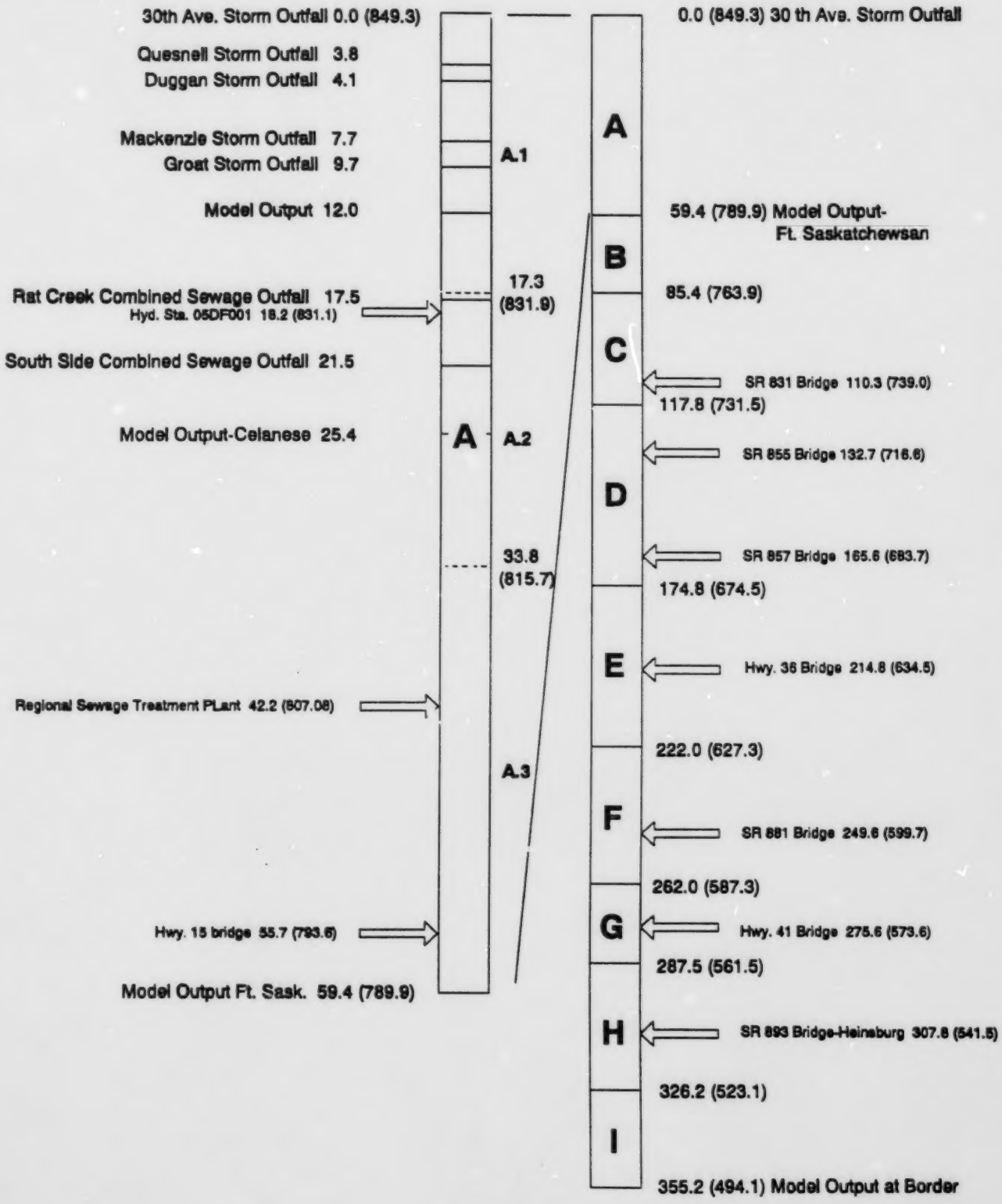
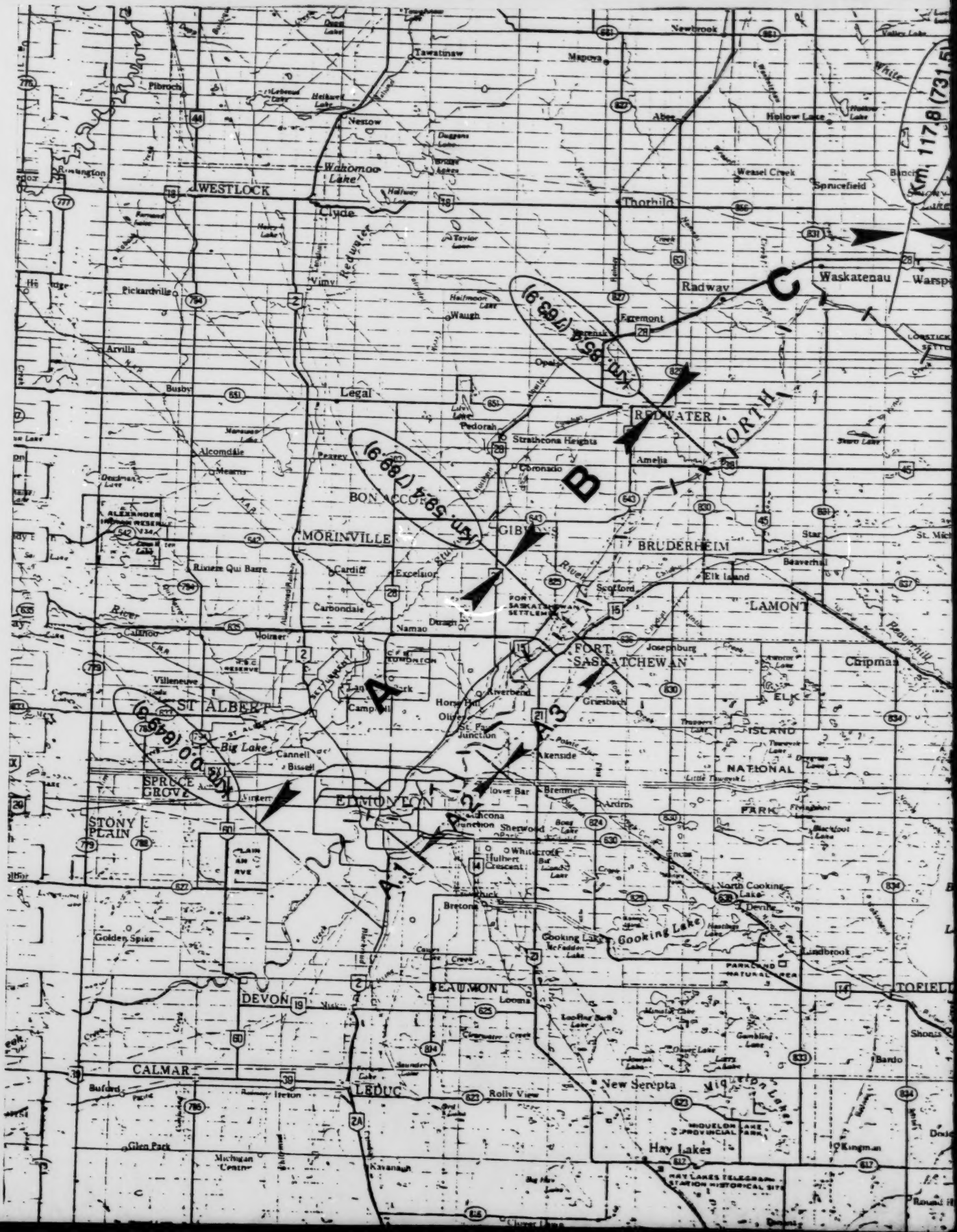


FIG. 1


Km. 117.8 (73.1)
Km. 85.4 (763.9)
Km. 58.4 (789.9)
Km. 0.0 (848.3)
A
B
C
NORTH
EDMONTON
WESTLOCK
Clyde
Thorhild
Waskatenau
Radway
Fremont
REDWATER
Legal
Pedorah
Strathcona Heights
Amelia
Coronado
BON ACCORD
GIBBONS
MORINVILLE
BRUDERHEIM
Star
Beaverhill
Elk Island
Scotford
LAMONT
Namao
FORT SASKATCHEWAN
Josephburg
Chipman
ELK ISLAND NATIONAL PARK
ST ALBERT
Big Lake
Cannell
Bissell
SPRUCE GROVE
STONY PLAIN
Golden Spike
Akenside
Bremner
Ardrossan
Sherwood
Whitecroft
Hulbert
Crescent
Bretona
North Cooking Lake
Cooking Lake
Lindbrook
TOFIELD
DEVON
BEAUMONT
CALMAR
LEDUC
New Serepta
Rolly View
Hay Lakes
Kingman
Bardo
Shonts
Glen Park
Kavanagh
Michigan Centre
Buford
Ireton
Alcomdale
Meanno
Busby
Arvilla
Pickardville
Pibroch
Nestow
Tawatinaw
Mapova
Newbrook
Abee
Hollow Lake
Weasel Creek
Sprucefield
Waugh
Opal
Pedorah
Riviere Qui Barre
Cardiff
Excelsior
Carbondale
Duagh
Calahoo
Wolmer
Villeneuve
Campbell
Horse Hill
Oliver
St Paul Junction
Riverbend
Gresbach
Fort Saskatchewan
Josephburg
Lamont
Elk Island
Beaverhill
Star
Waskatenau
Radway
Thorhild
Clyde
Westlock
Redwater
Bon Accord
Morinville
St Albert
Edmonton
Spruce Grove
Stony Plain
Devon
Beaumont
Calmar
Leduc
New Serepta
Hay Lakes
Tofield
Lindbrook
Kingman
Bardo
Shonts
Golden Spike
Glen Park
Kavanagh
Michigan Centre
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Arvilla
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Mapova
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Devon
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New Serepta
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Kingman
Bardo
Shonts
Glen Park
Kavanagh
Michigan Centre
Buford
Ireton

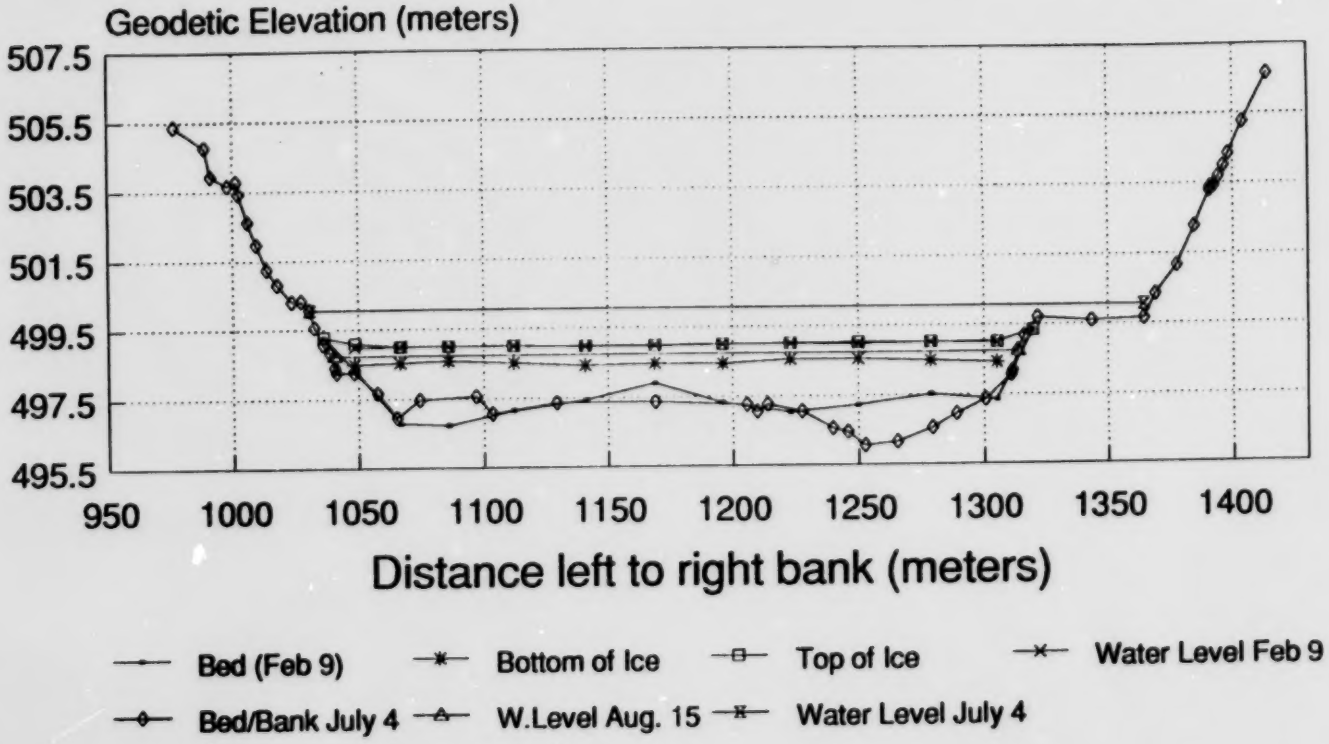
NOTE:
(Km. XXX.X (YYY.Y) translates as:
XXX.X = Planning's distances
YYY.Y = P.F.R.A. distances

FIG 2
REACH AND
CROSS SECTION LOCATIONS

NORTH SASKATCHEWAN RIVER

Km 494.1

1990 Winter & Summer Surveys

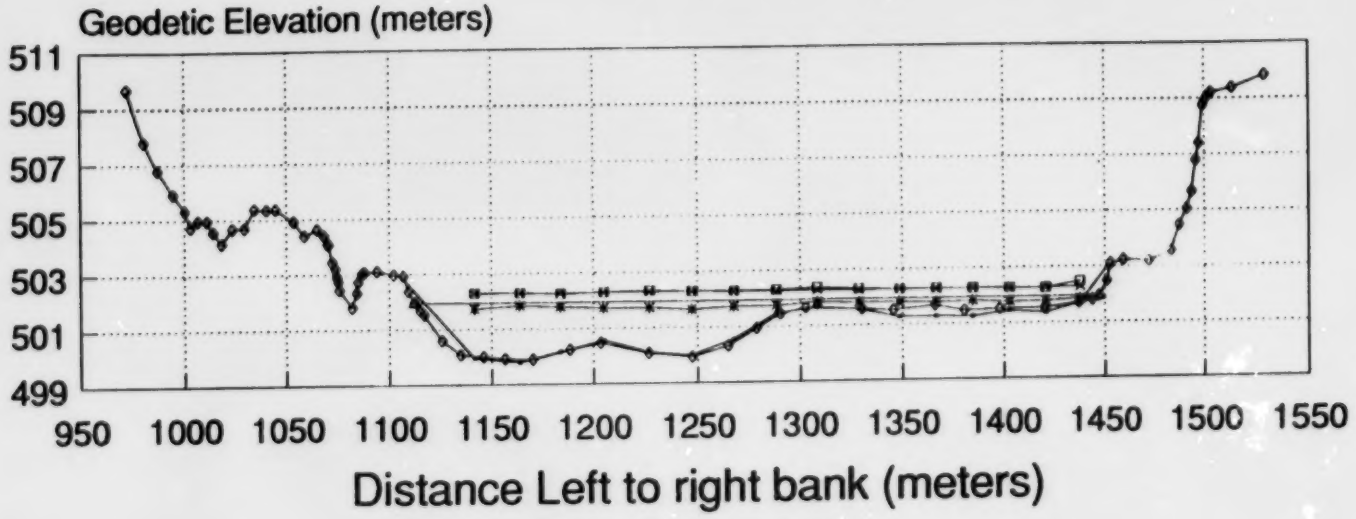


Hamilton & Olsen (Feb. 9)
A. Environment (July 4 & Aug. 15)

N. SASK. R., N. Hutt. Colony

Km. 512.2

1990 Winter & Summer Surveys

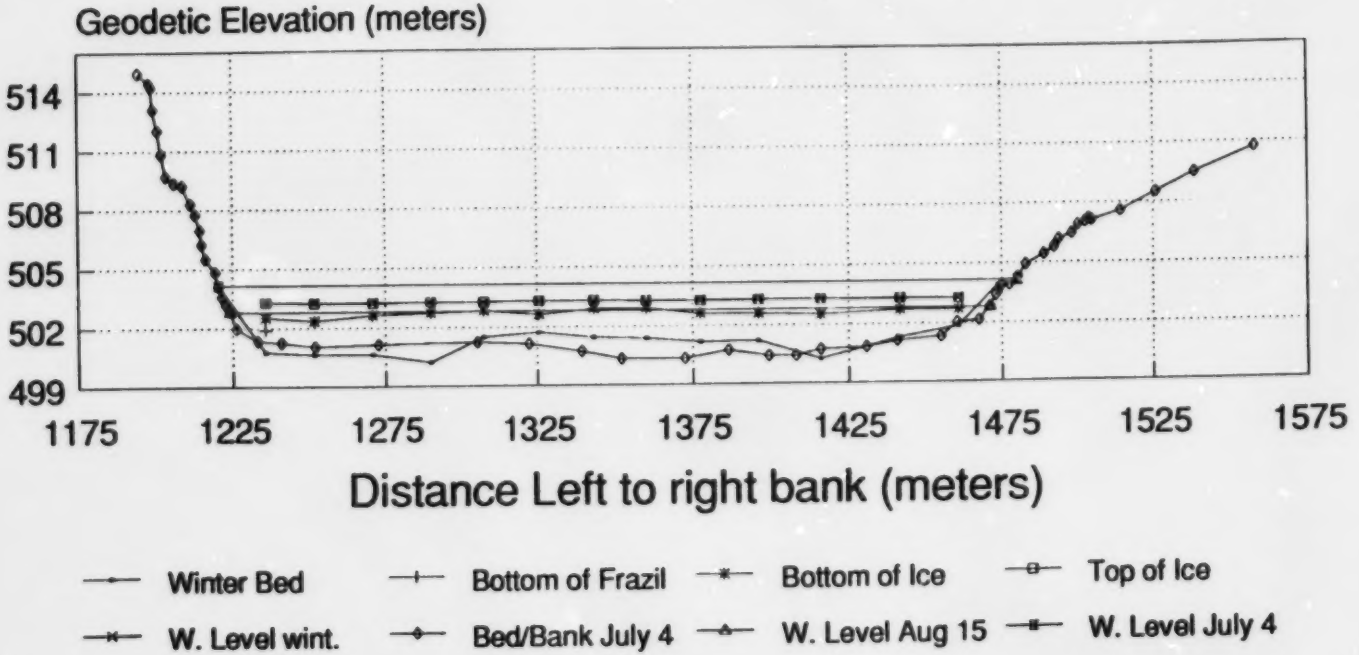


Hamilton & Olsen (Feb. 8)
Alberta Environment (July 4)

N. SASK. R., by Hutterite Colony

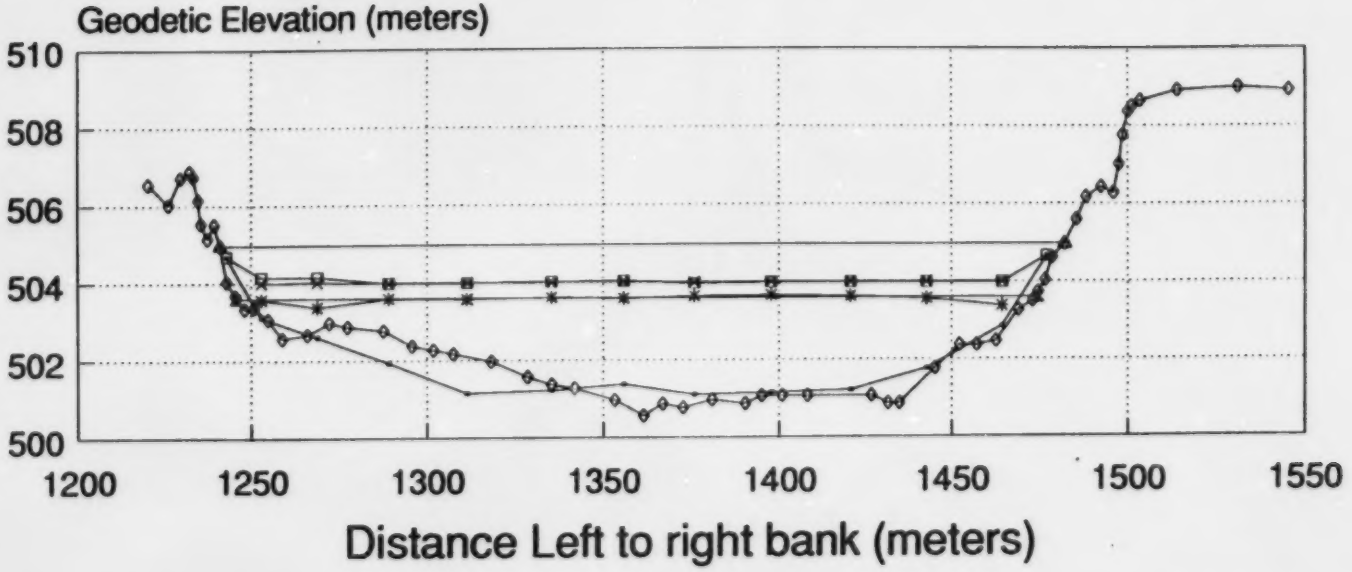
Km. 517.7

1990 Winter & Summer Surveys



Hamilton & Olsen (Feb. 8)
Alberta Environment (summer)

N. SASK. R., 55 m. u/s Hwy 897 Br.
Km. 522.1
1990 Winter & Summer Surveys



Hamilton & Olsen (Feb. 9)
Alberta Environment (summer)

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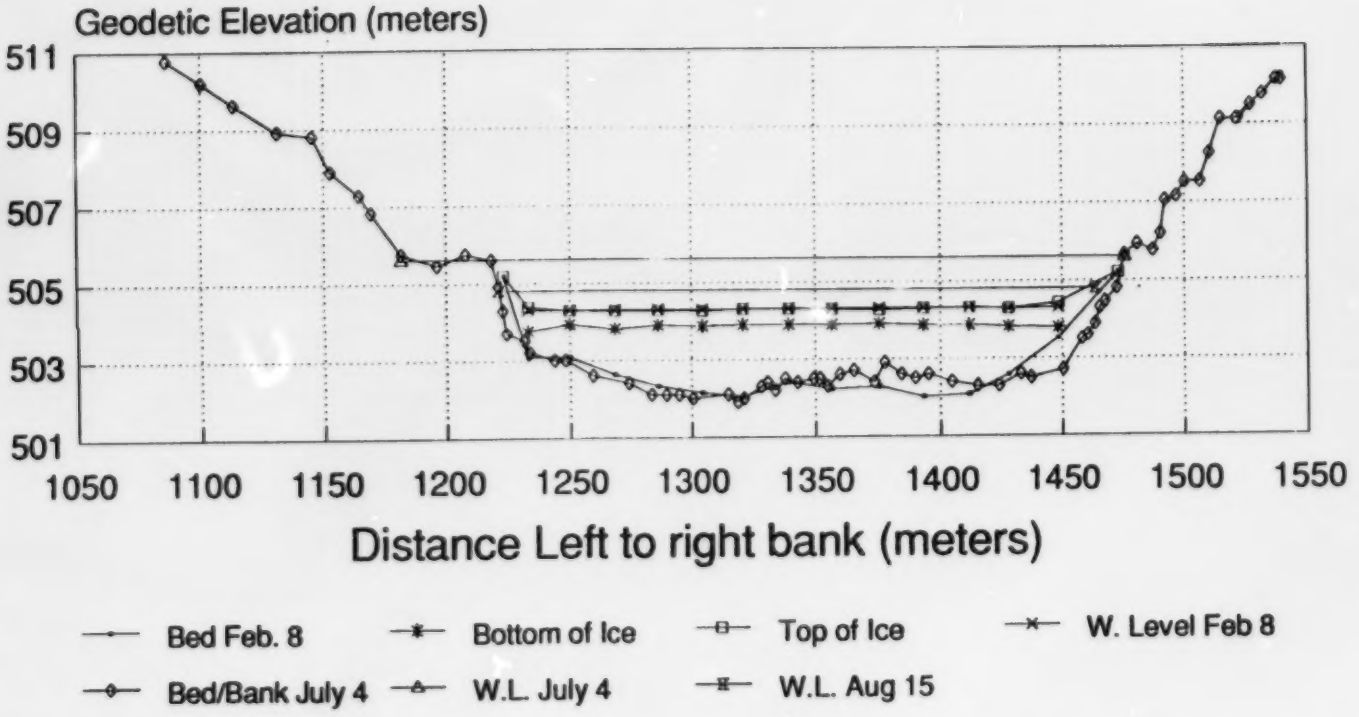
1990 Summer & Winter Surveys



Hamilton & Olsen (Feb. 8)
Alberta Environment (July 4)

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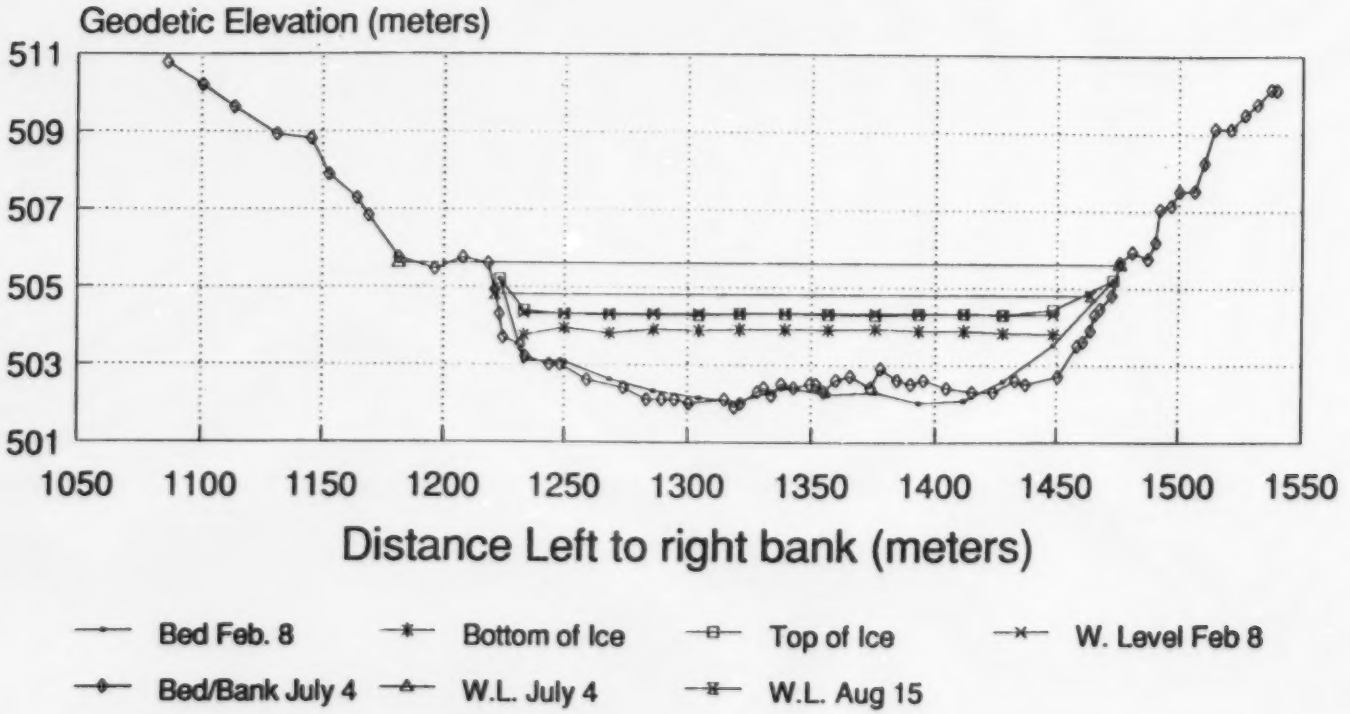
1990 Summer & Winter Surveys



Hamilton & Olsen (Feb. 8)
Alberta Environment (July & Aug)

NORTH SASKATCHEWAN RIVER
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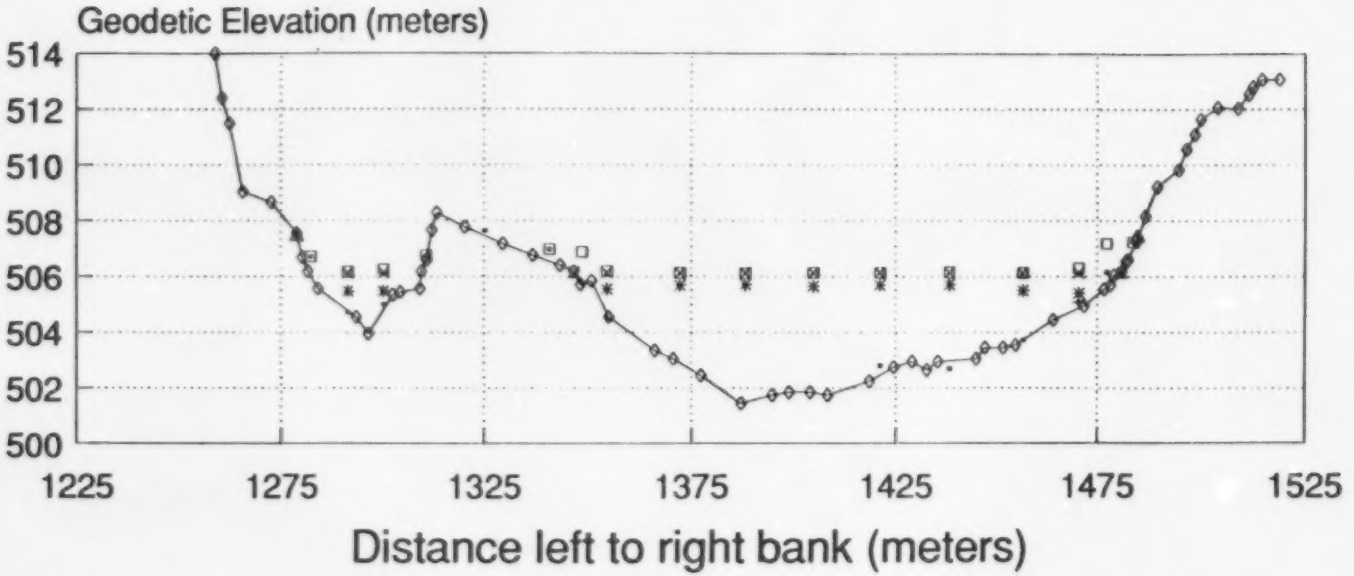
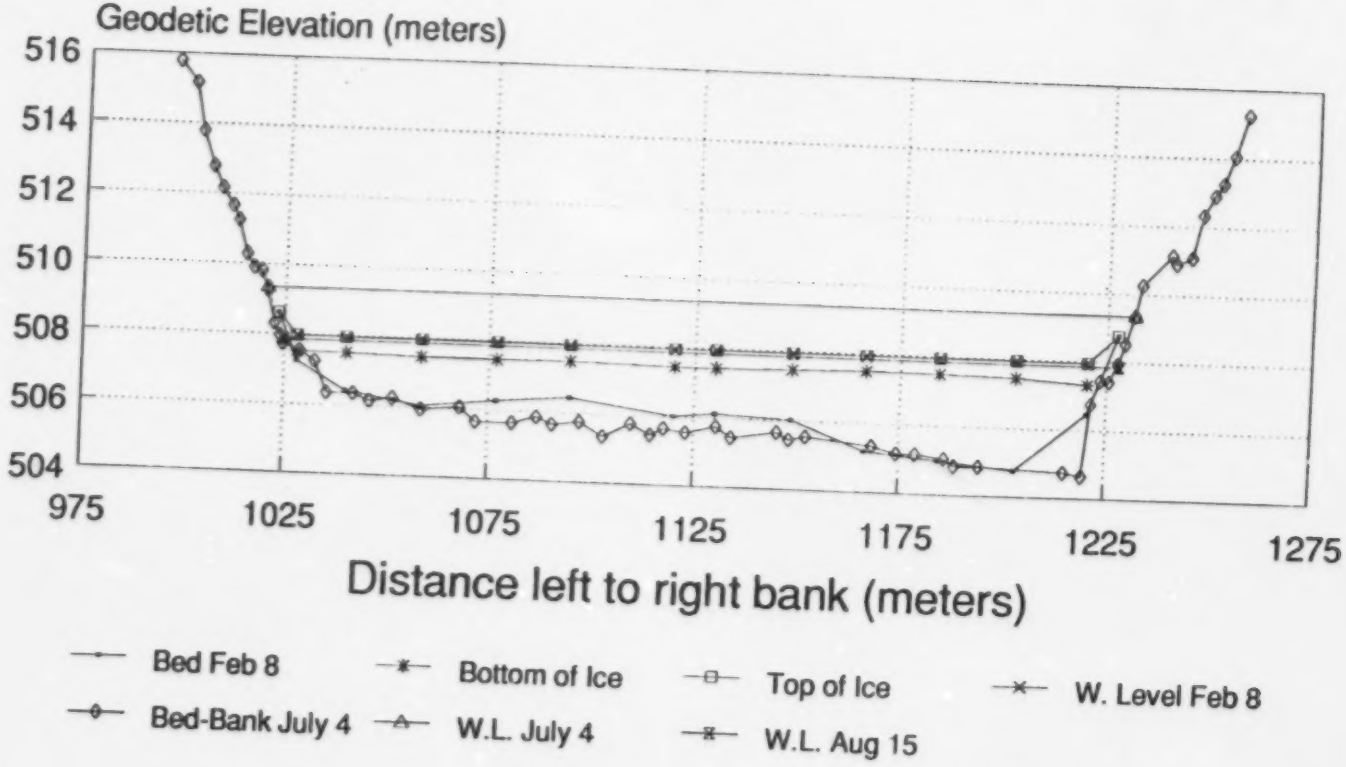
1990 Summer & Winter Surveys



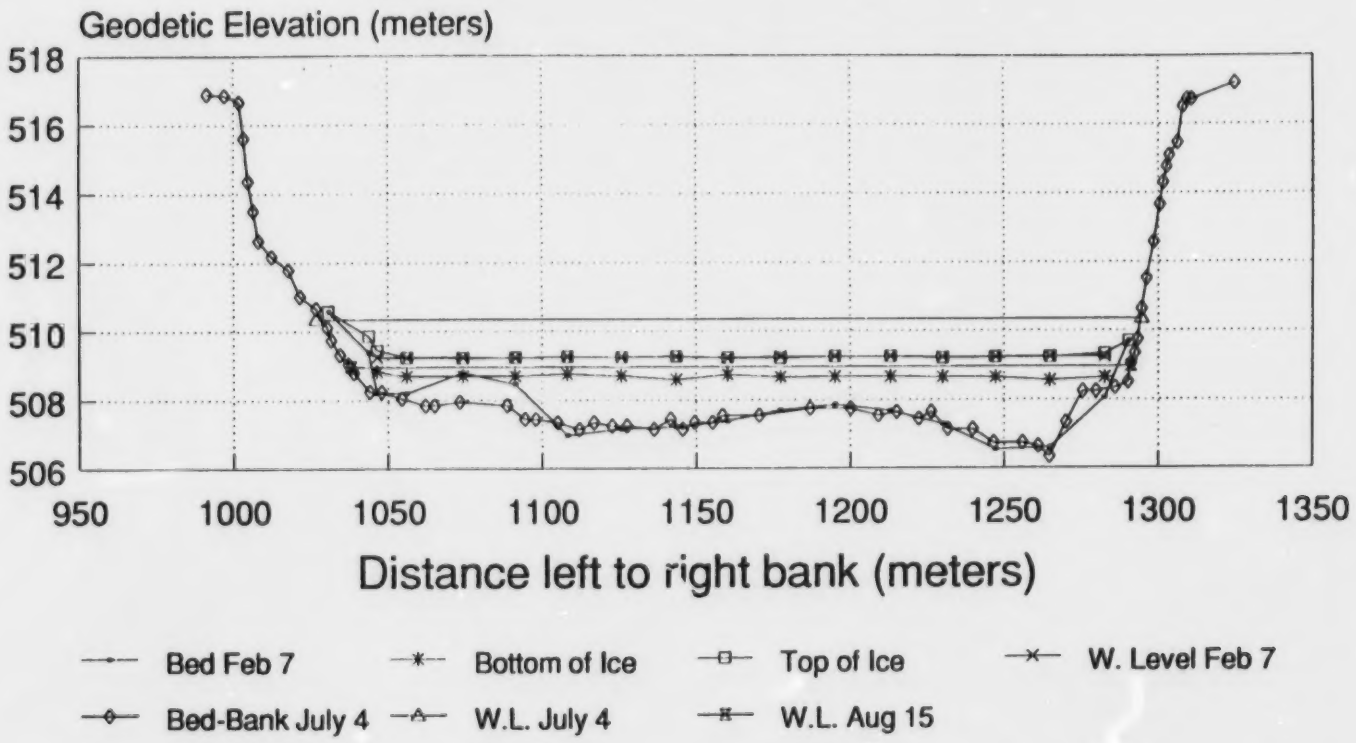
Hamilton & Olsen (Feb 8)
Alberta Environment (July & Aug)

NORTH SASKATCHEWAN RIVER
Km. 540.5
1990 Summer & Winter Surveys



Hamilton & Olsen (Feb. 8)
Alberta Environment (July & Aug)

NORTH SASKATCHEWAN RIVER
Km. 549.7
1990 Winter & Summer Surveys

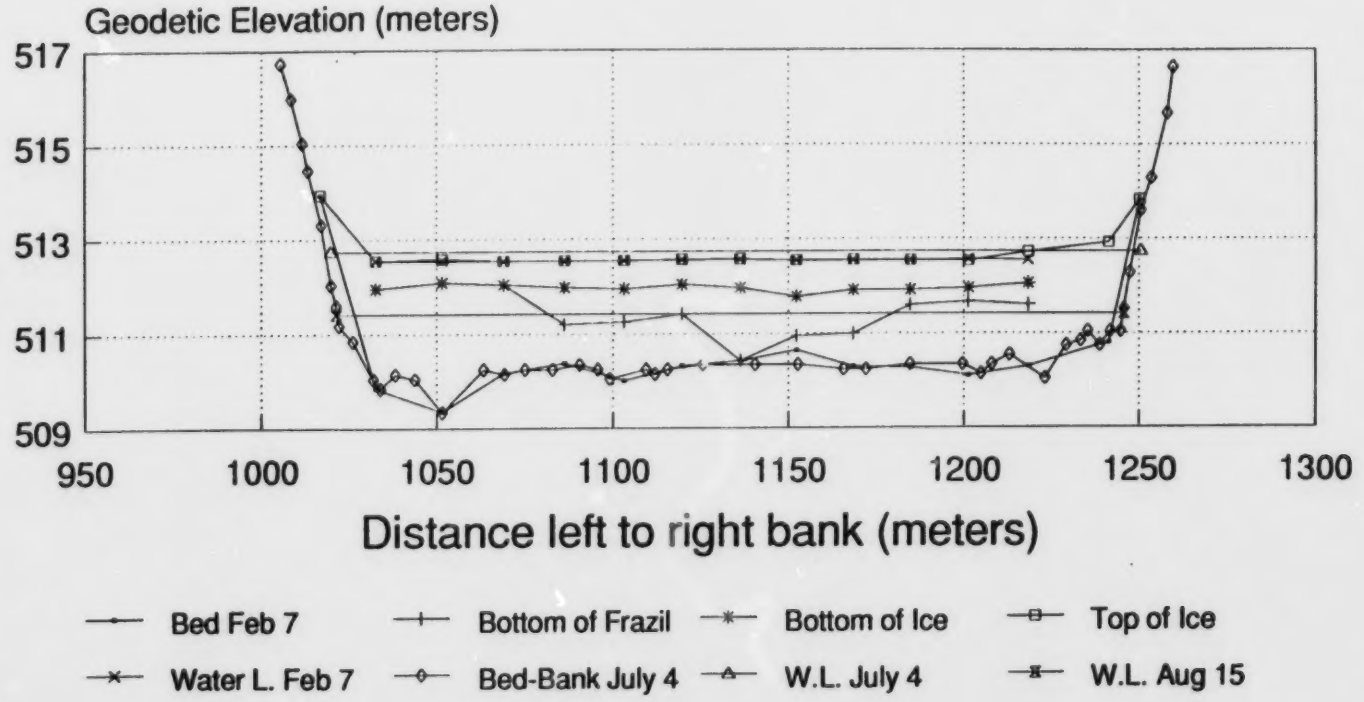


Hamilton & Olsen (Feb. 7)
Alberta Environment (July & Aug)

NORTH SASKATCHEWAN RIVER

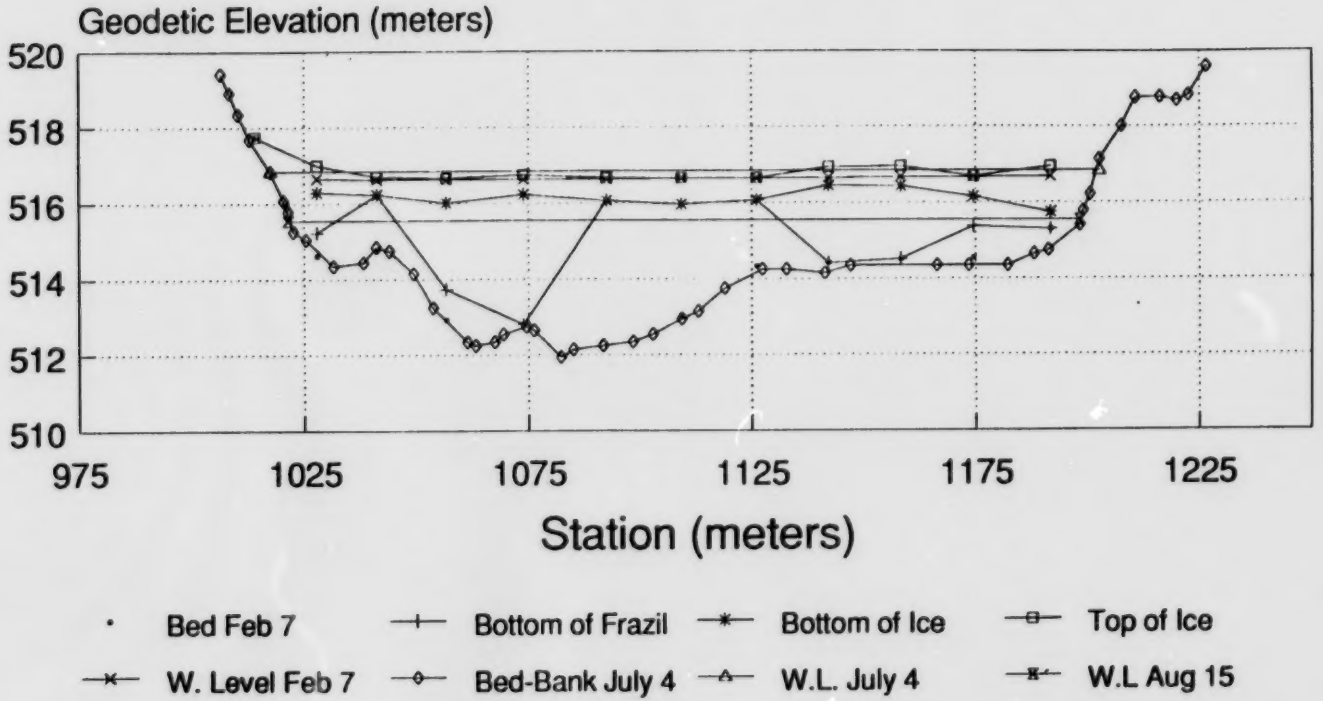
Km. 555.1

1990 Winter & Summer Surveys



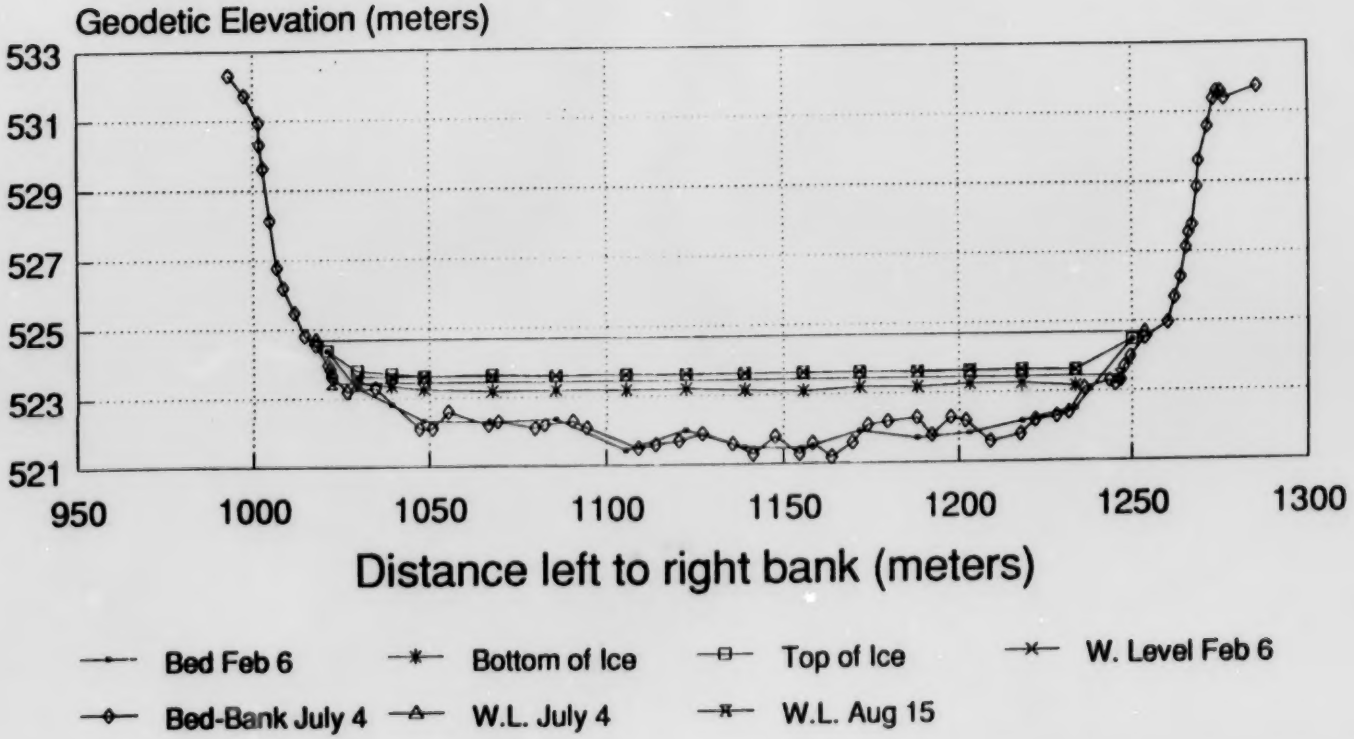
Hamilton & Olsen (Feb. 7)
Alberta Environment (July & Aug)
Some upper bank data omited both banks

NORTH SASK. R.-S. of Archeological Site
Km. 564.2
1990 Winter & Summer Surveys



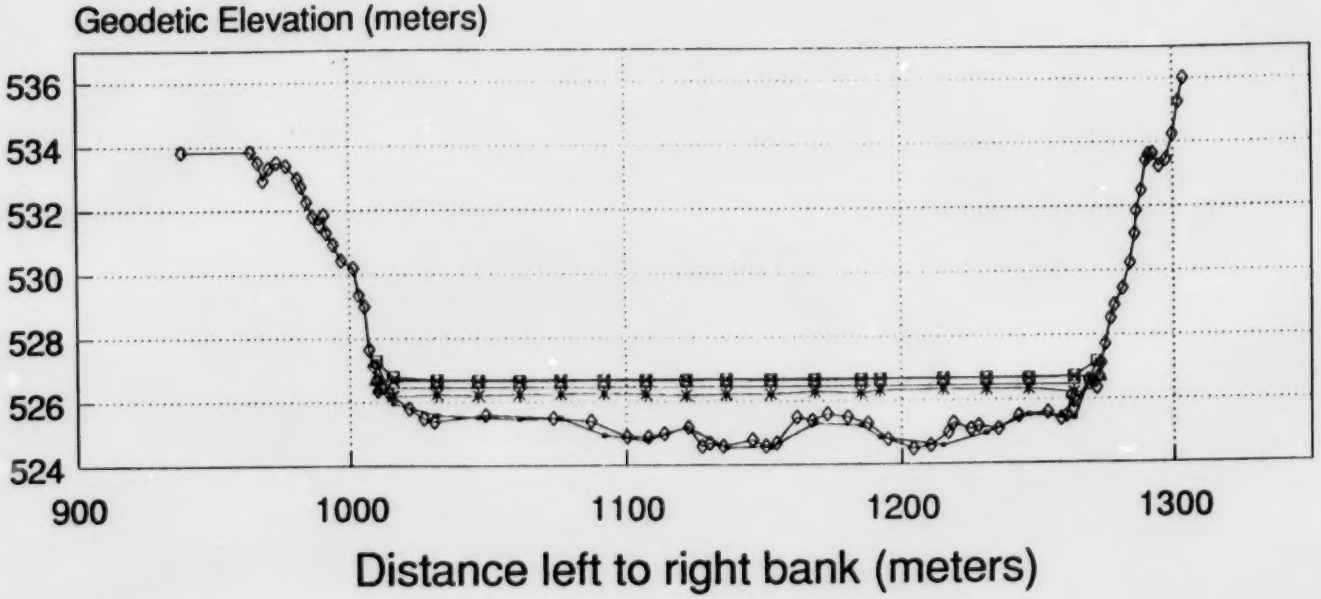
Hamilton & Olsen (Feb. 7)
Alberta Environment (July & August)
Some AE upper bank data omitted

NORTH SASKATCHEWAN RIVER
km. 574.1
1990 Winter & Summer Surveys



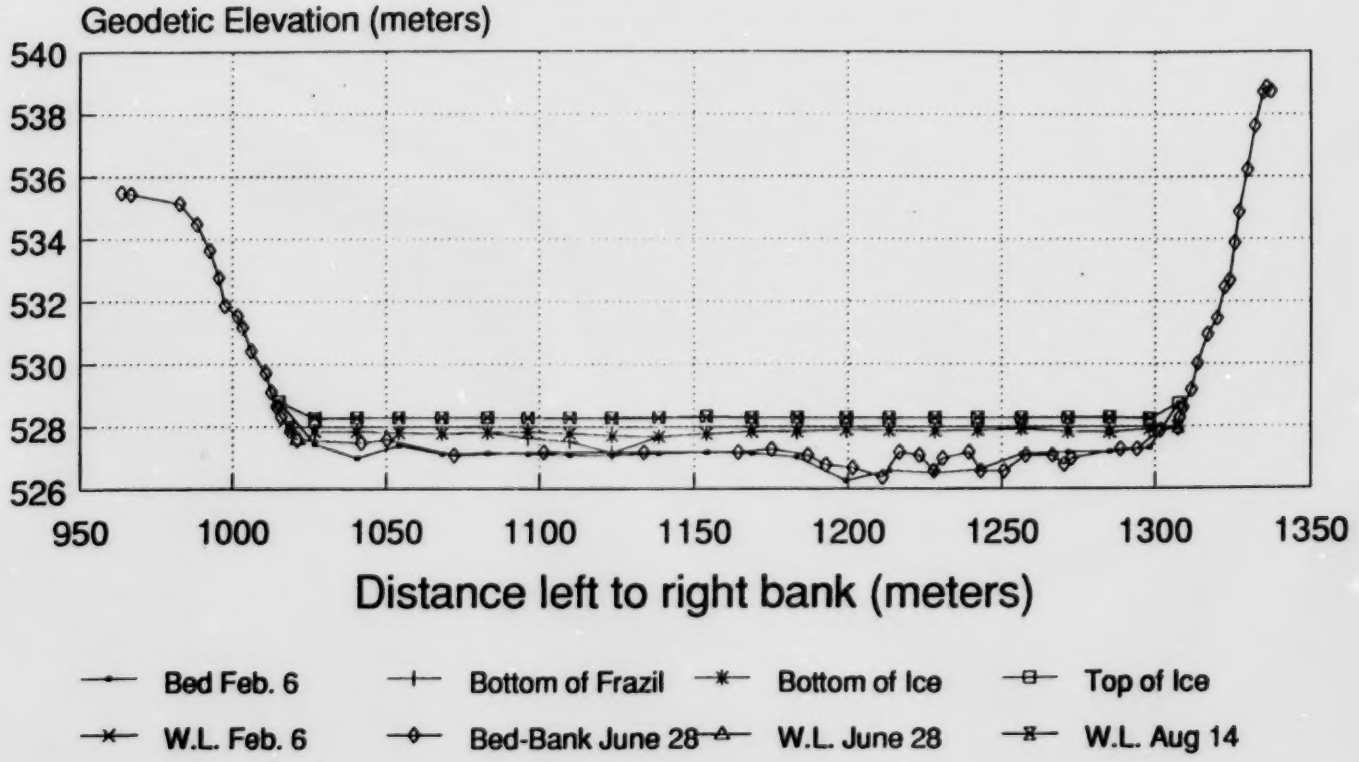
Hamilton & Olsen (Feb. 6)
Alberta Environment (July & August)_

NORTH SASKATCHEWAN RIVER
km. 589.2
1990 Winter & Summer Surveys



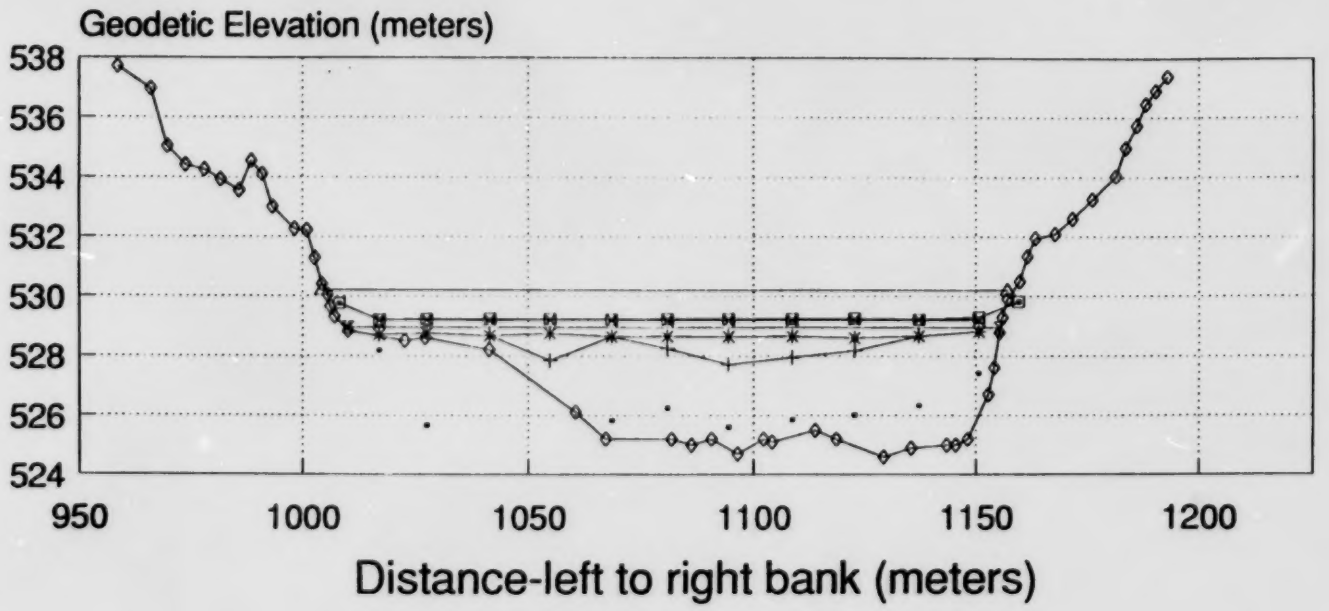
Hamilton & Olsen (Feb. 6)
Alberta Environment (June & Aug)

NORTH SASKATCHEWAN RIVER
Downstream of Fort Island Km. 593.3
1990 Winter & Summer Survey



Hamilton & Olsen (Feb. 6)
Alberta Environment (June & Aug)

NORTH SASKATCHEWAN RIVER
Downstream Hwy. 881 bridge, Km. 599.2
1990 Winter & Summer Surveys

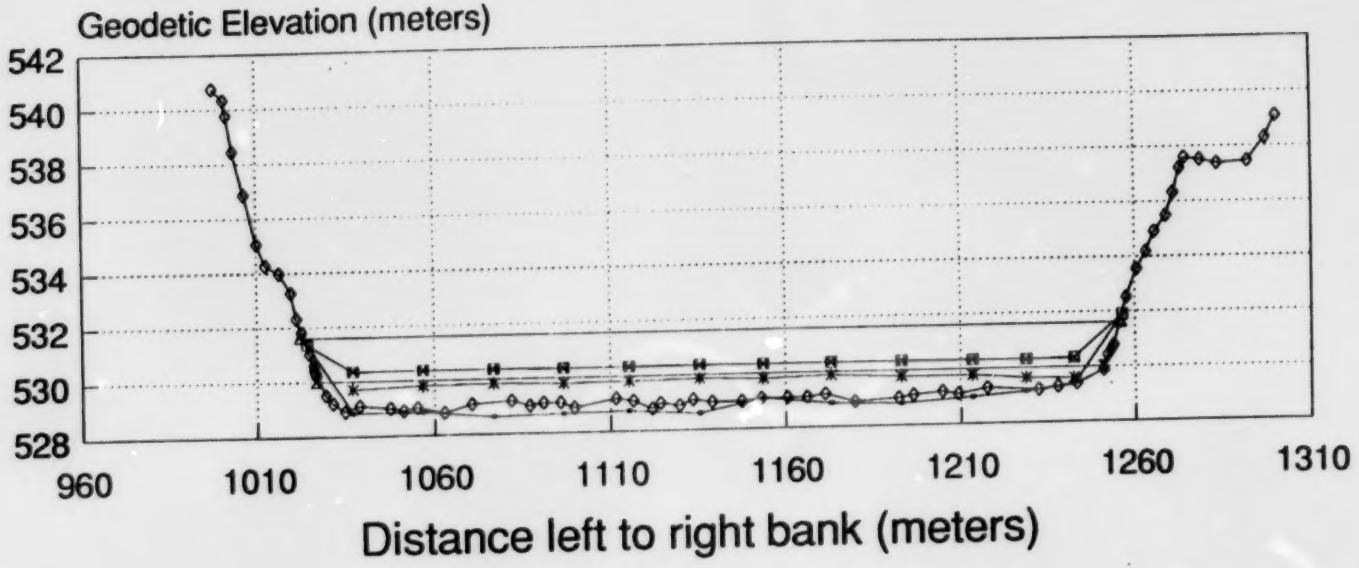


Hamilton & Olsen (Feb)
Alberta Environment (June & Aug)

NORTH SASKATCHEWAN RIVER

Km. 608.4

1990 winter and summer surveys

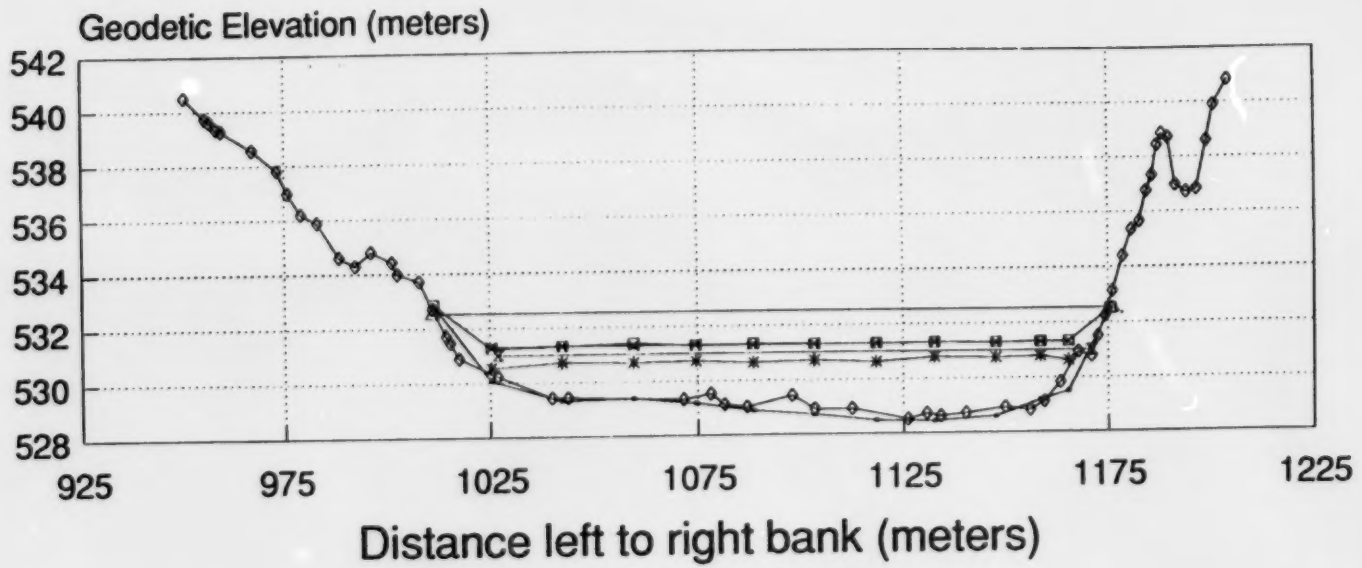


Hamilton & Olsen (Jan)
Alberta Environment (June)
*Bed June 28, Banks Aug. 2

NORTH SASKATCHEWAN RIVER

Kilometer 612.1

1990 Winter & Summer survey

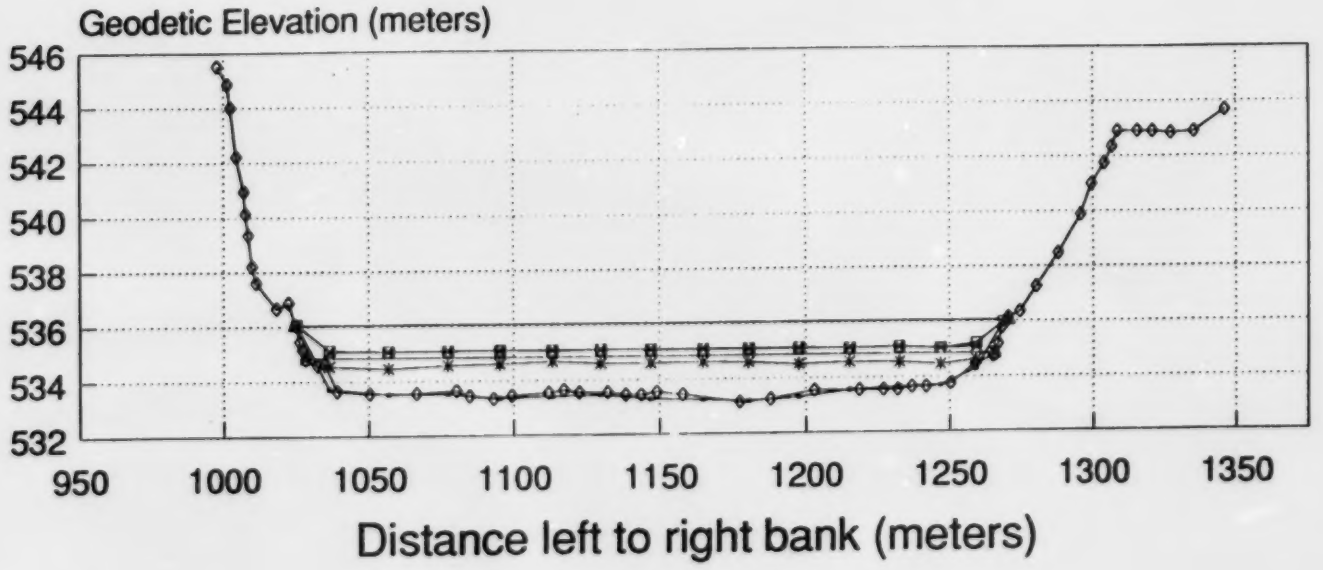


Hamilton & Olsen (winter)
Alberta Environment (summer)
*Bed surveyd June 28 Bank Aug 1

NORTH SASKATCHEWAN RIVER

km. 625.4

1990 Winter & Summer Surveys

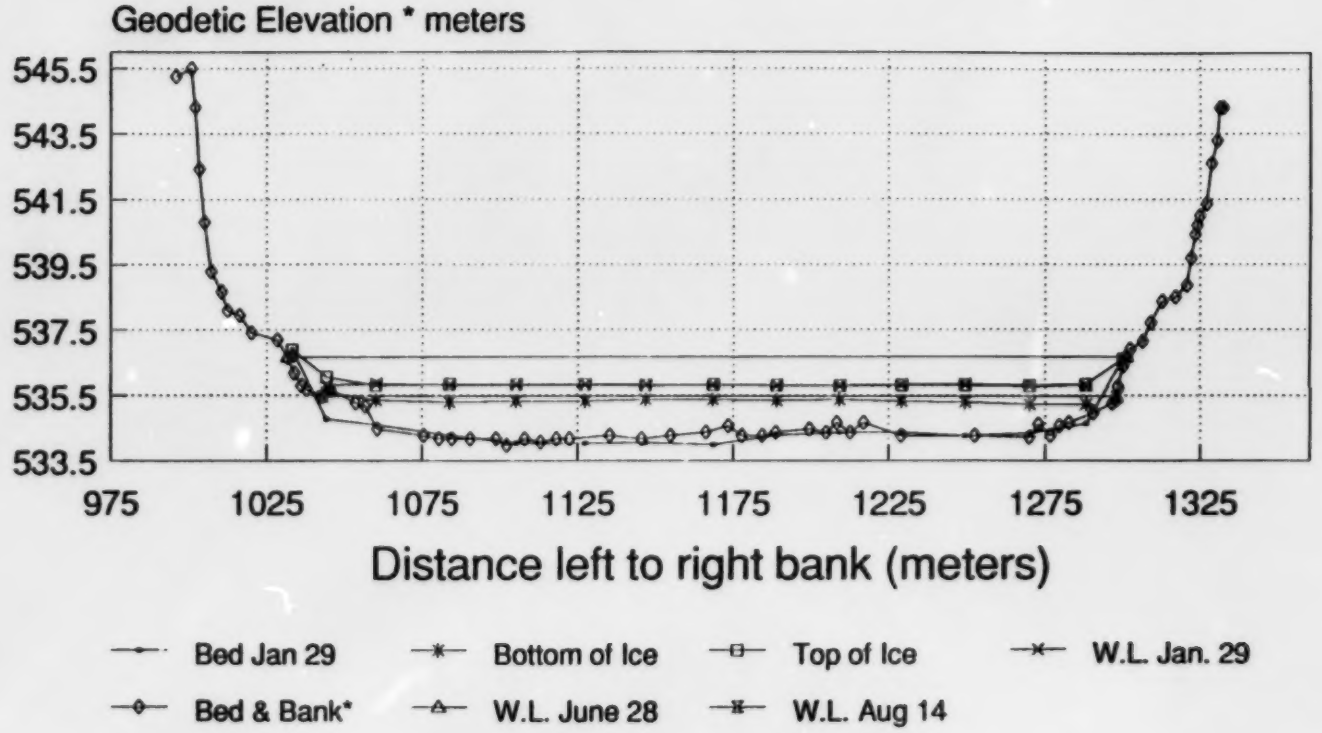


Hamilton & Olsen Feb 5/90
Alberta Environment (summer)
Bed sounded June 28 bank surv. Aug. 1

NORTH SASKATCHEWAN RIVER

Km. 630.0

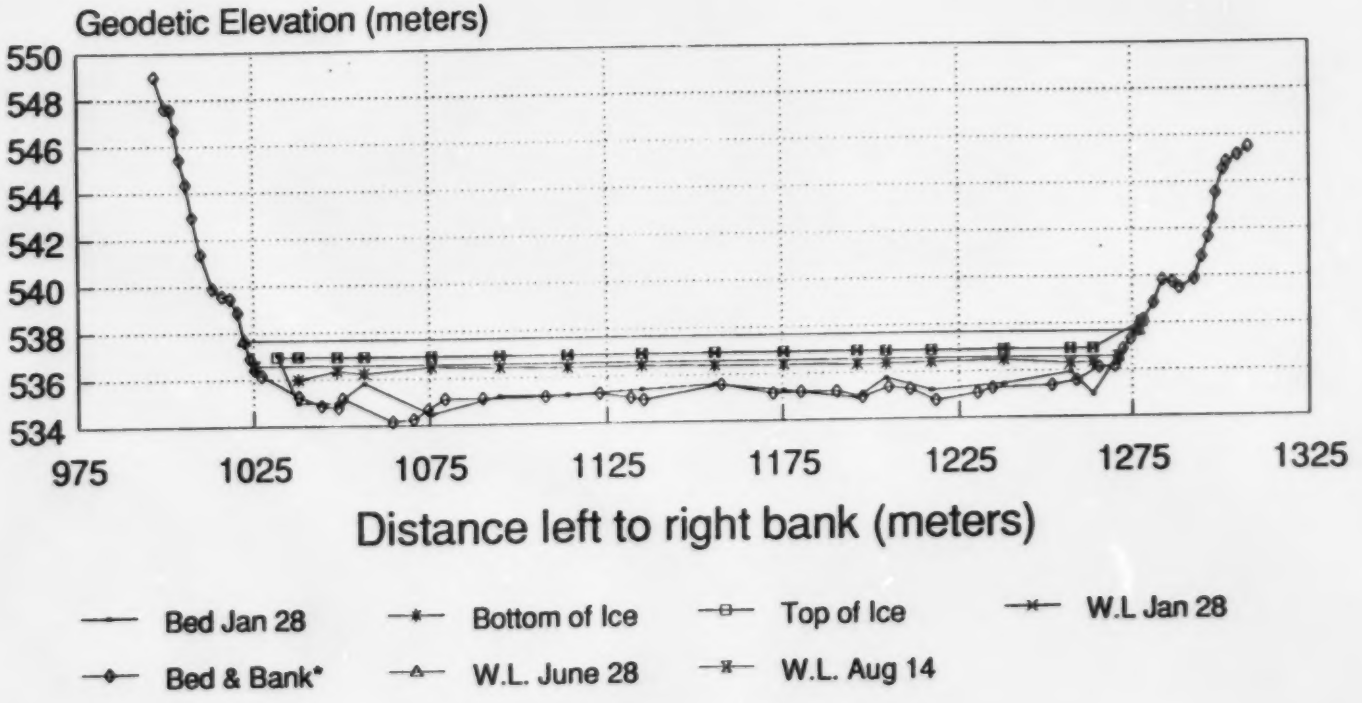
1990 Winter & Summer Surveys



Hamilton & Olsen (Jan 29)
Alberta Environment (summer)

*Bed sounded June 28 Bank surv. Aug. 1

NORTH SASKATCHEWAN RIVER
km 634.5, 170 m. d/s of Duvernay bridge.
1990 Winter & Summer Surveys

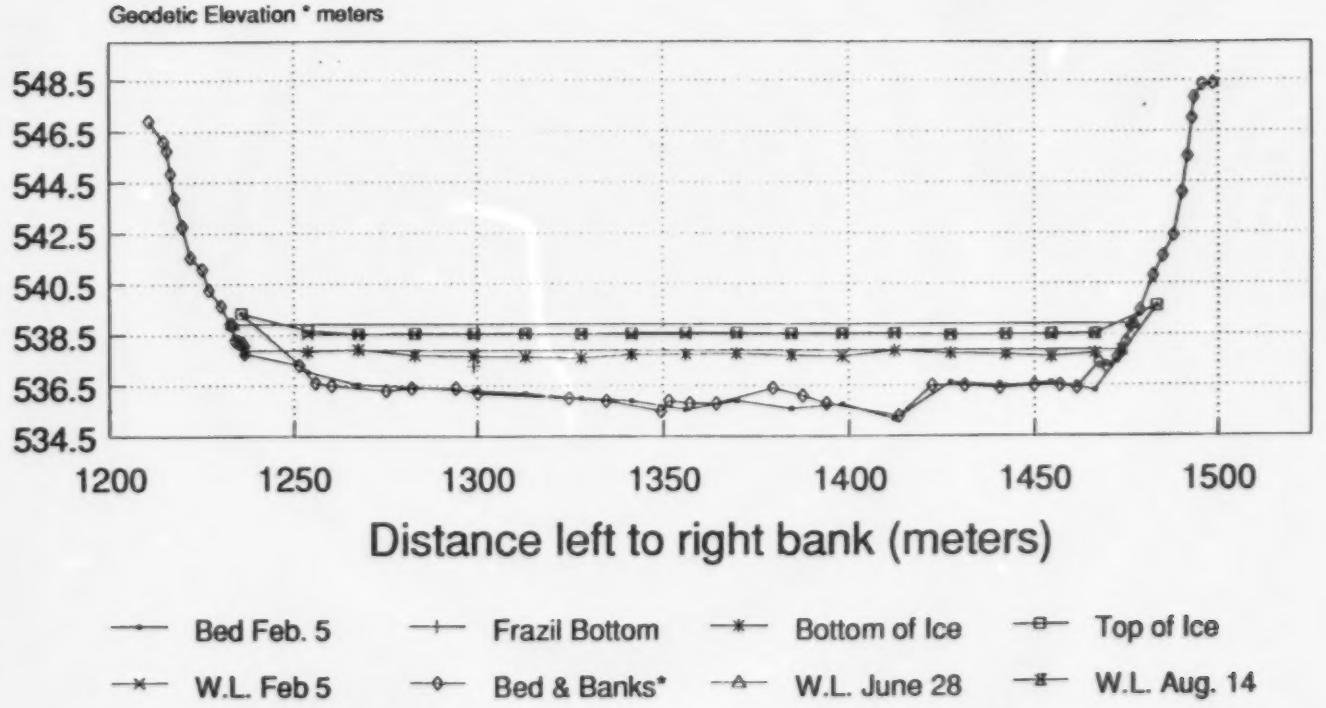


Hamilton & Olsen (Jan.28)
Alberta Environment (summer)
*Bed sounded June 28 Bank surveyed Aug 1

NORTH SASKATCHEWAN RIVER

Kilometer 637.9

1990 Winter & Summer Surveys

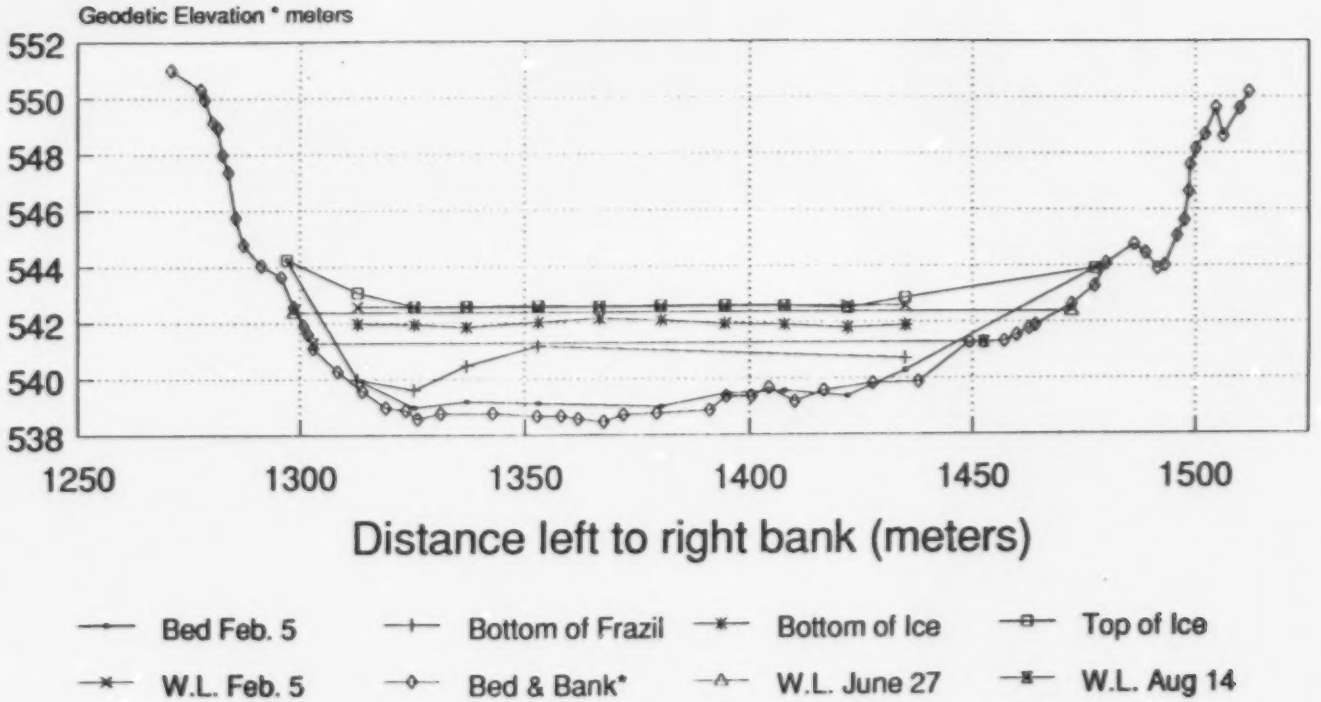


Hamilton & Olsen (Feb 5)
Alberta Environment (summer)
*Bed sounded June 28 Bank survey Aug 1

NORTH SASKATCHEWAN RIVER

Kilometer 649.5

1990 Winter & Summer Surveys

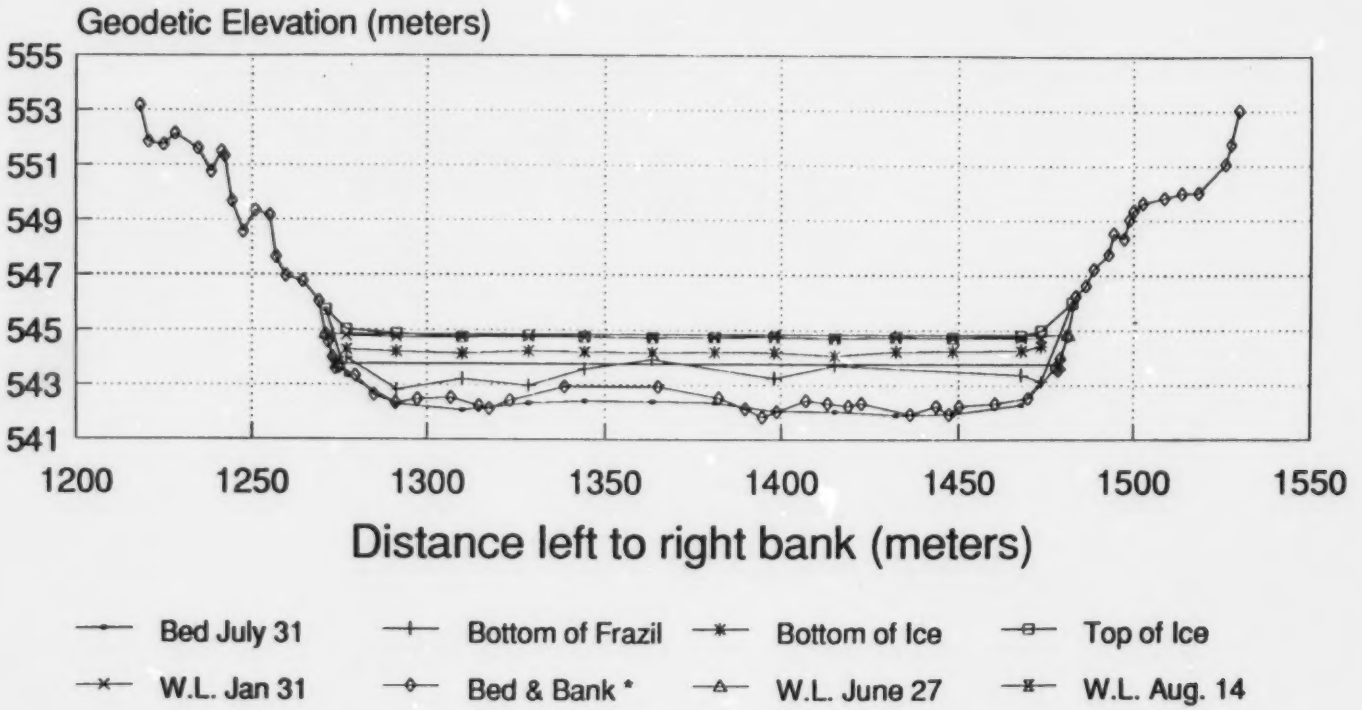


Hamilton & Olsen (Feb. 5)
Alberta Environment (June 27)
*Bed sounded June 27 Bank survey Aug. 1

NORTH SASKATCHEWAN RIVER

kilometer 653.3

1990 Winter & Summer Surveys

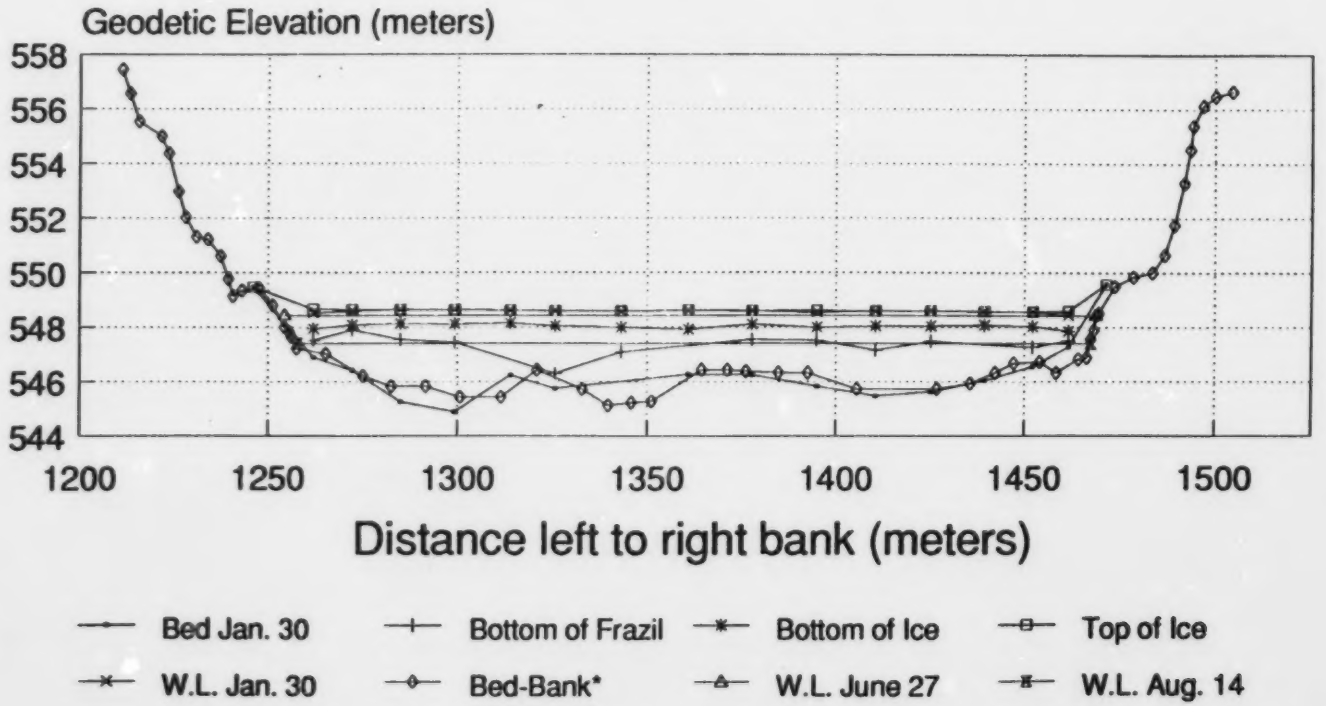


Hamilton & Olsen (Jan 31)
Alberta Environment (summer)
*Bed sounded June 27 Bank survey July 31

NORTH SASKATCHEWAN RIVER

Kilometer 663.9

1990 Winter & Summer Surveys

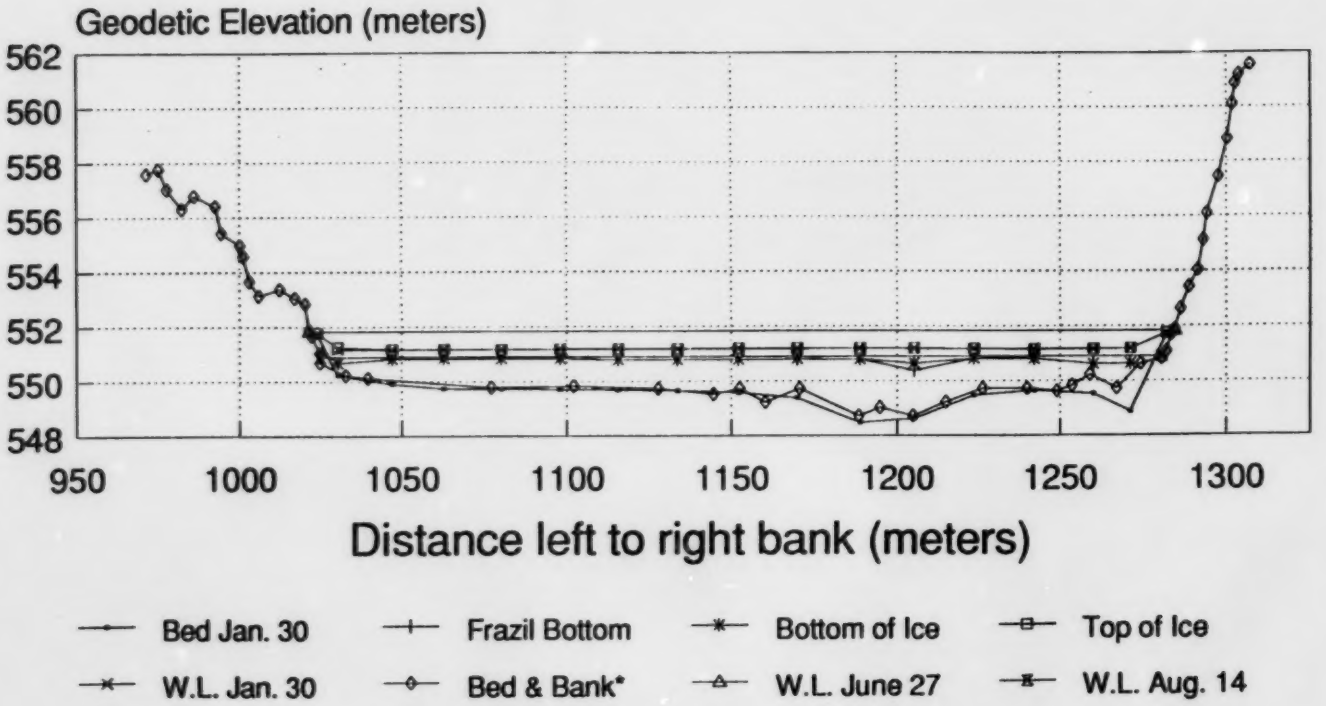


Hamilton & Olsen (Jan 30)
Alberta Environment (summer)
*Bed sounded June 27 bank survey July 31

NORTH SASKATCHEWAN RIVER

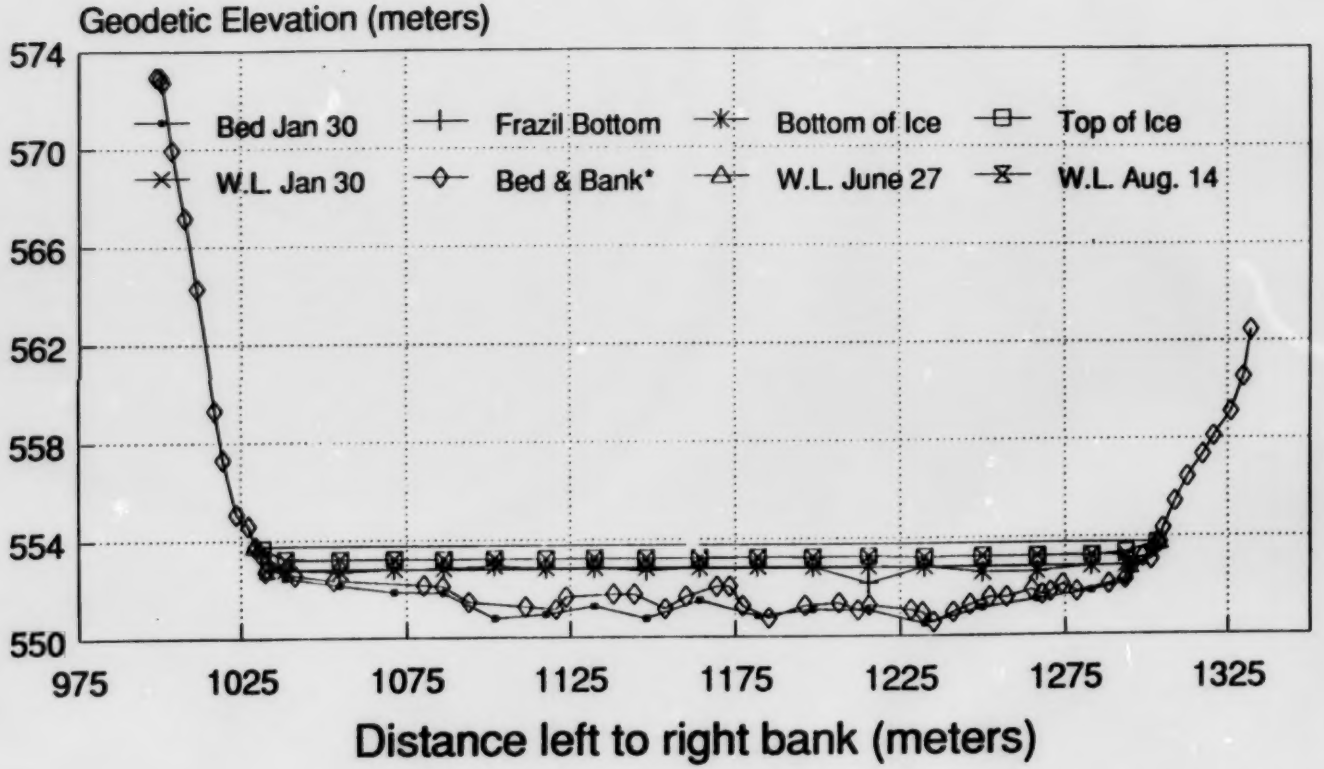
kilometer 668.7

1990 Winter & Summer Surveys



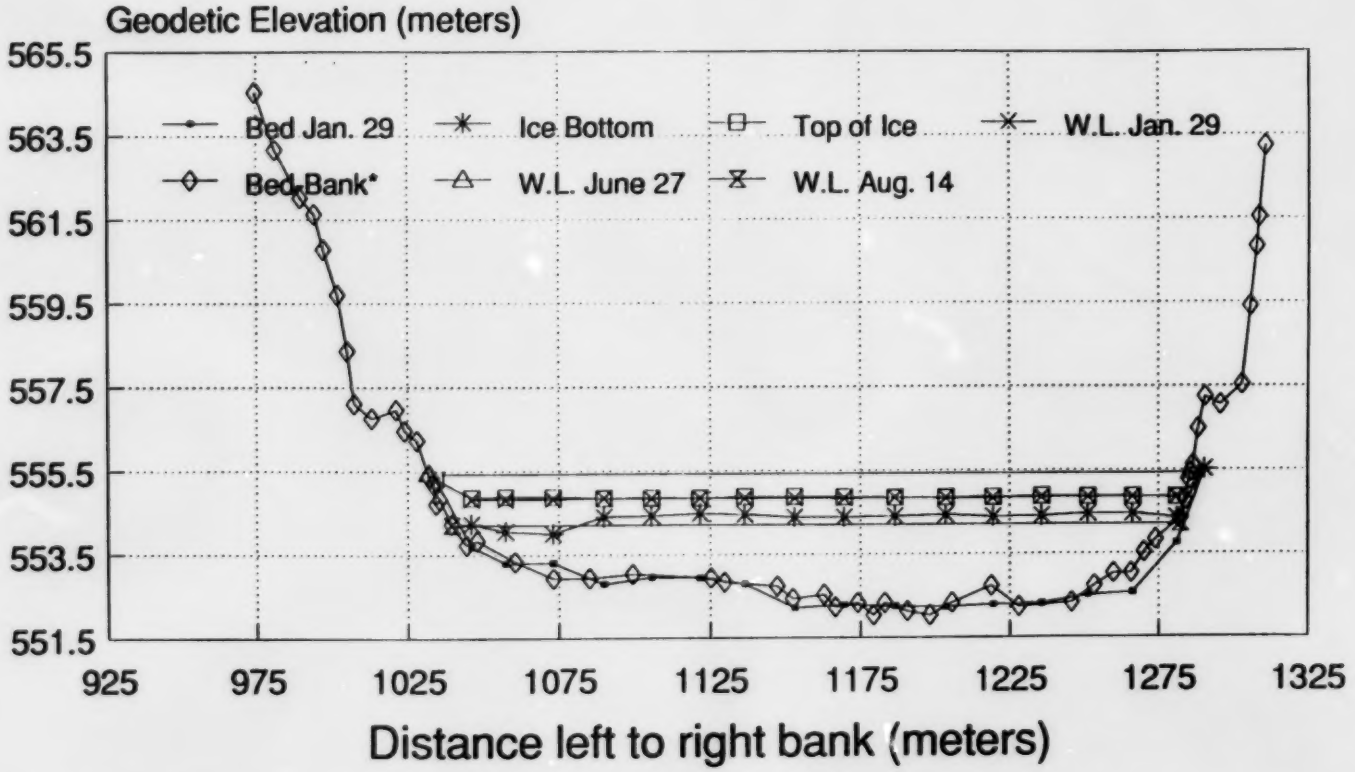
Hamilton & Olsen (Jan. 30)
Alberta Environment (June 27)
*Bed sounded June 27 Bank survey July 19

NORTH SASKATCHEWAN RIVER
Kilometer 676.9
1990 Winter & Summer Surveys



Hamilton & Olsen (Jan 30)
Alberta Environment (June 27)
*Bed sounded June 27 Bank survey July 19

NORTH SASKATCHEWAN RIVER
Km. 683.7, Downstream of Shandro Bridge
1990 Winter & Summer Surveys

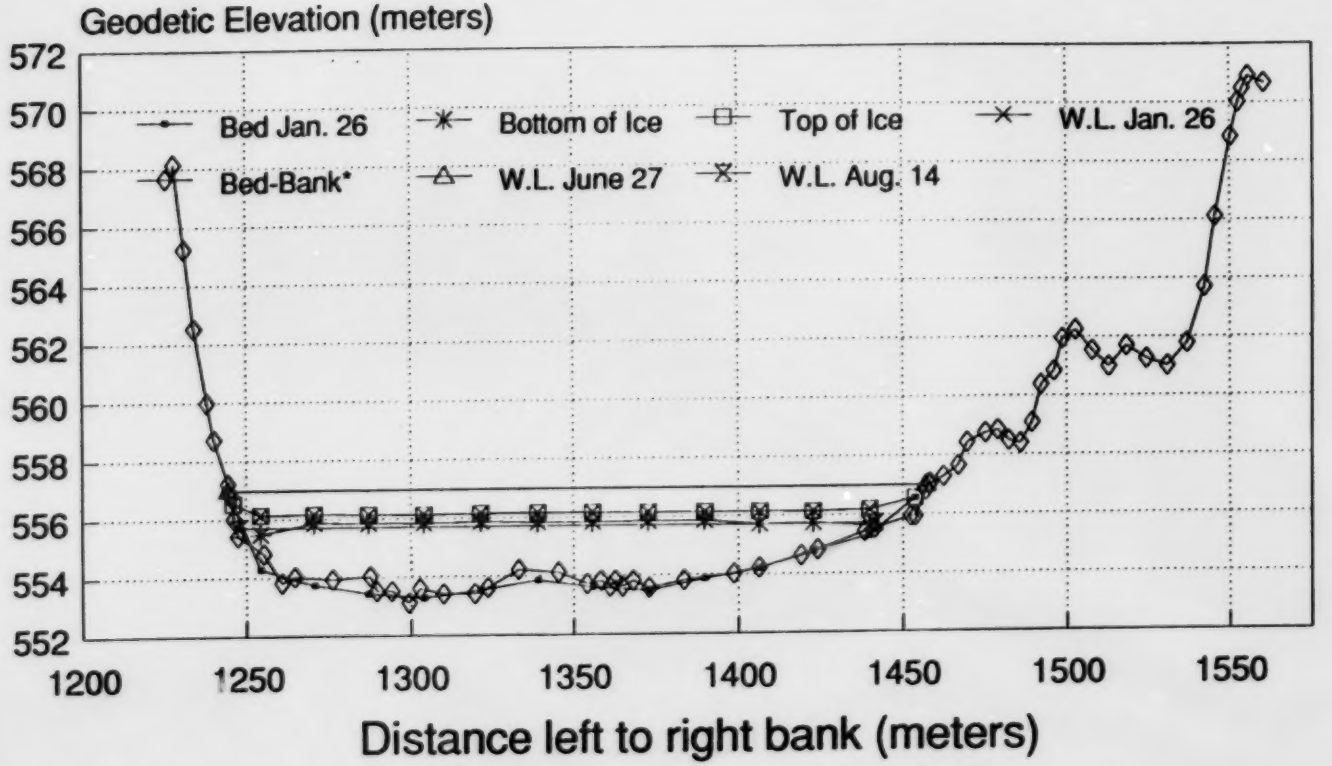


Hamilton & Olsen (Jan 29)
Alberta Environment (Summer)
*Bed sounded June 27 Bank Survey July 19

NORTH SASKATCHEWAN RIVER

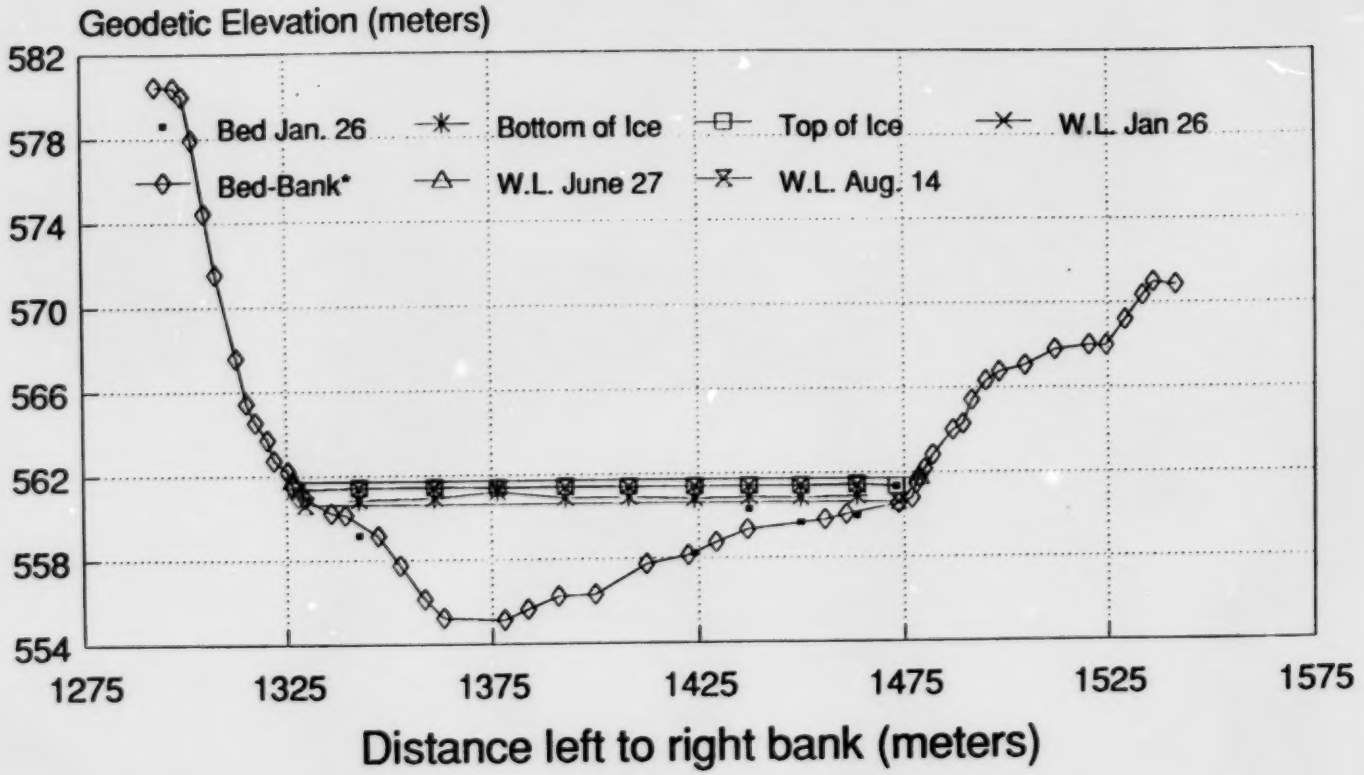
Kilometer 690.8

1990 Winter & Summer Survey



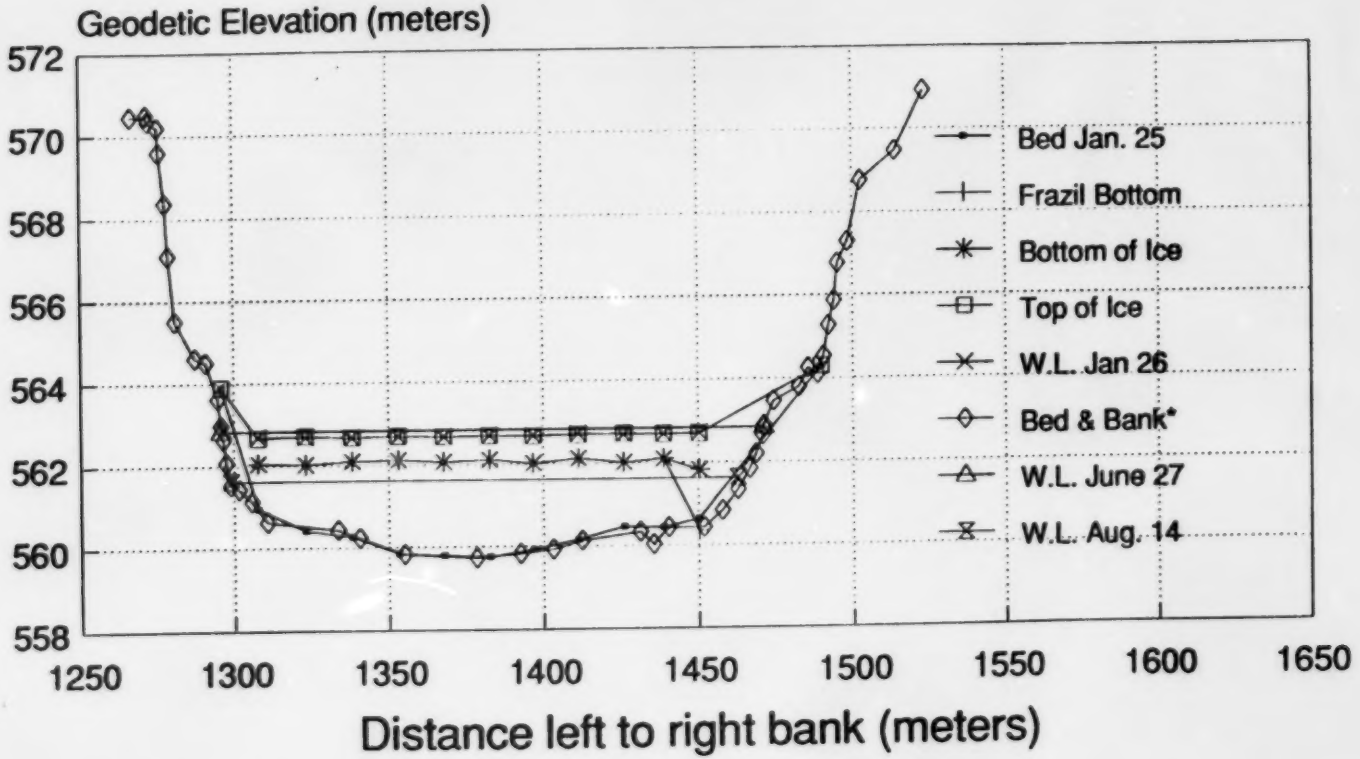
Hamilton & Olsen (Jan. 26)
Alberta Environment (summer)
*Bed sounded June 27 Bank survey July 19

NORTH SASKATCHEWAN RIVER
Km. 703.1, D/S of log cabin 60 meters
1990 Winter & Summer Survey



Hamilton & Olsen (Jan 26)
Alberta Environment (June 27)
*Bed sounded June 27 Bank survey July 18

NORTH SASKATCHEWAN RIVER
Kilometer 706.3, Beach Area
1990 Winter & Summer Surveys

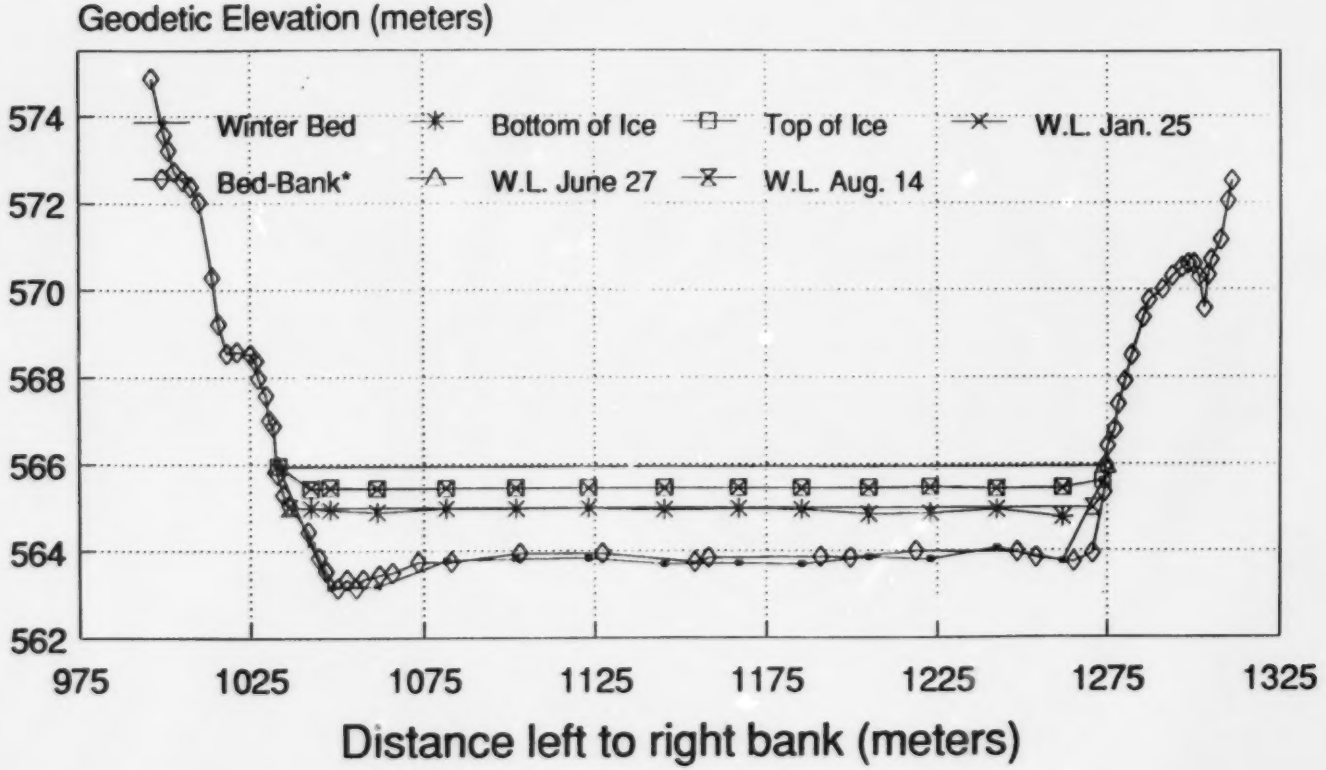


Hamilton & Olsen (Jan 25 & 26)
*A. Env. bed sounding June 27 & Bank
Survey July 18

NORTH SASKATCHEWAN RIVER

Km. 710.9, (Pakan Ferry Site)

1990 Winter & Summer Survey

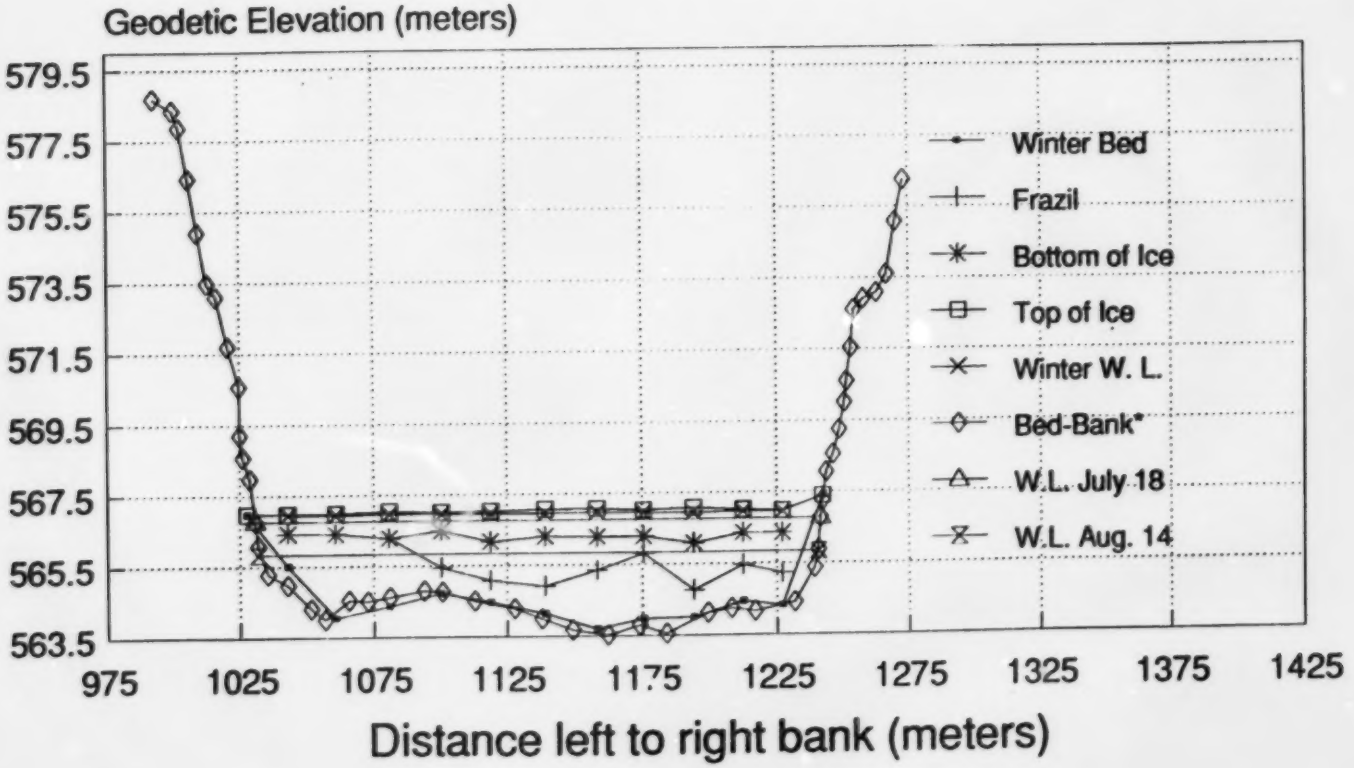


Hamilton & Olsen (Jan. 25)
*A. Env. Sounding June 27 Bank survey
July 18

NORTH SASKATCHEWAN RIVER

Km. 716.6, (u/s Pakan Bridge)

1990 Winter & Summer Survey

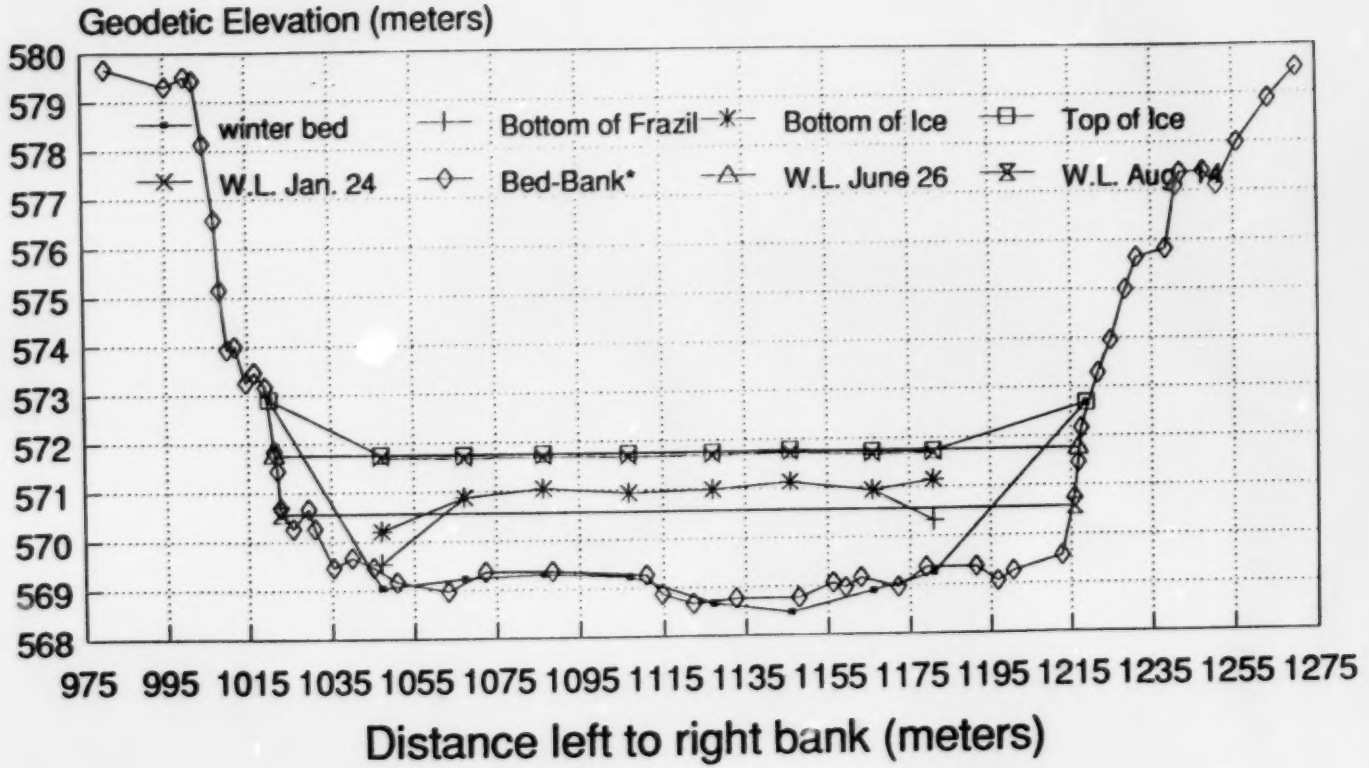


Hamilton & Olsen (Jan 25)
*A. Env. bed sounding ? &
Bank survey July 18

NORTH SASKATCHEWAN Combined 1990 Surveys

Km. 726.8 by Lobstick Settlement

Winter (Jan 24) & Summer (June 26)

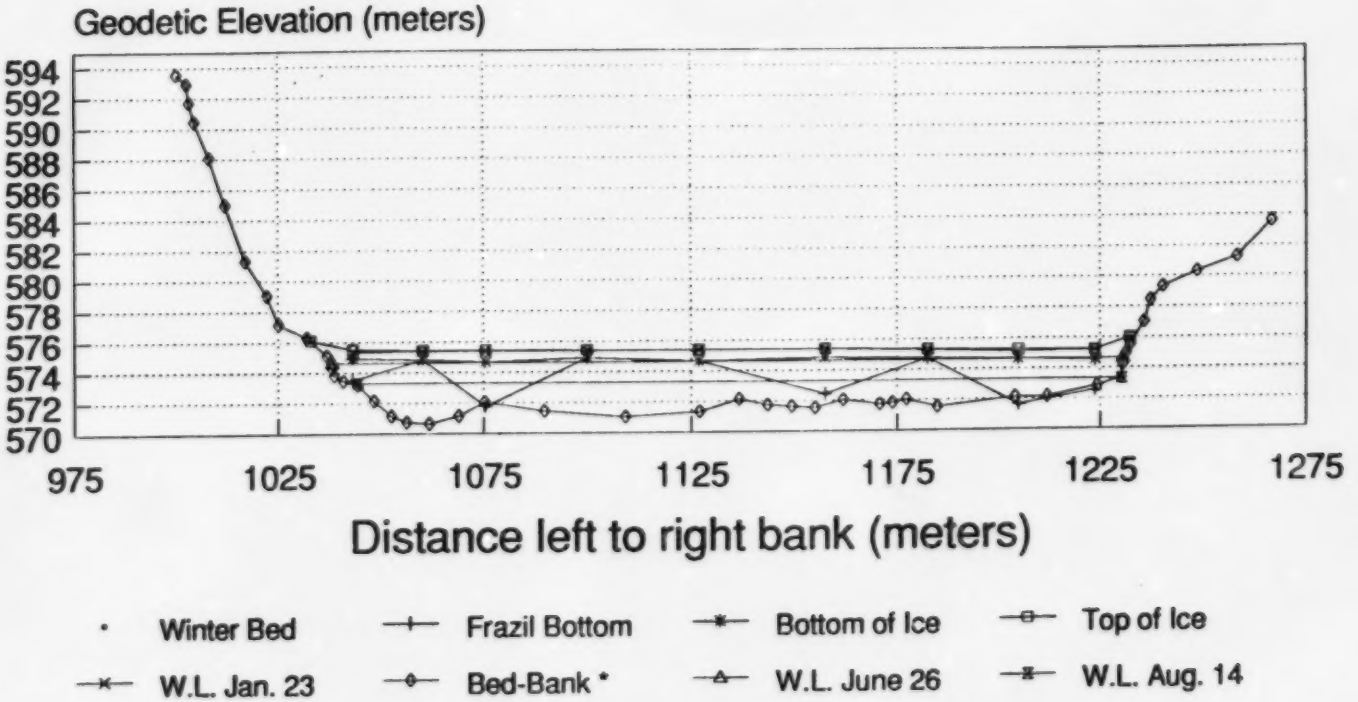


Winter survey (Jan. 24) Hamilton & Olsen
Summer Survey by Alberta Environment
*Bed sound June 26 Bank survey July 18

NORTH SASKATCHEWAN RIVER

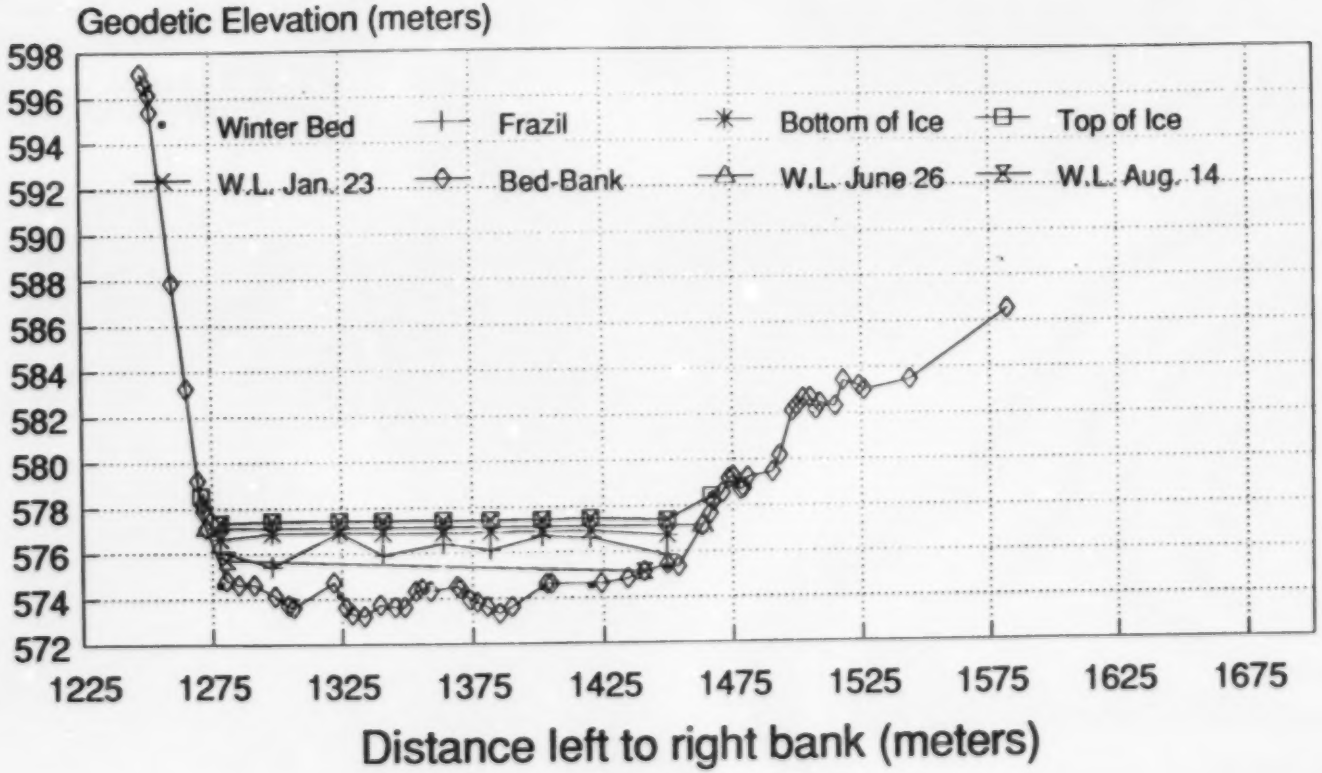
Km. 733.2-Vicinity of Katylak Farm

1990 Winter & Summer Survey



Hamilton & Olsen (Jan 23)
Alberta Environment (summer)
*Bed sound June 26 Bank survey July 17

NORTH SASKATCHEWAN RIVER
km. 739.0 - 200 m. u/s Waskatenau bridge
1990 Winter & Summer Surveys

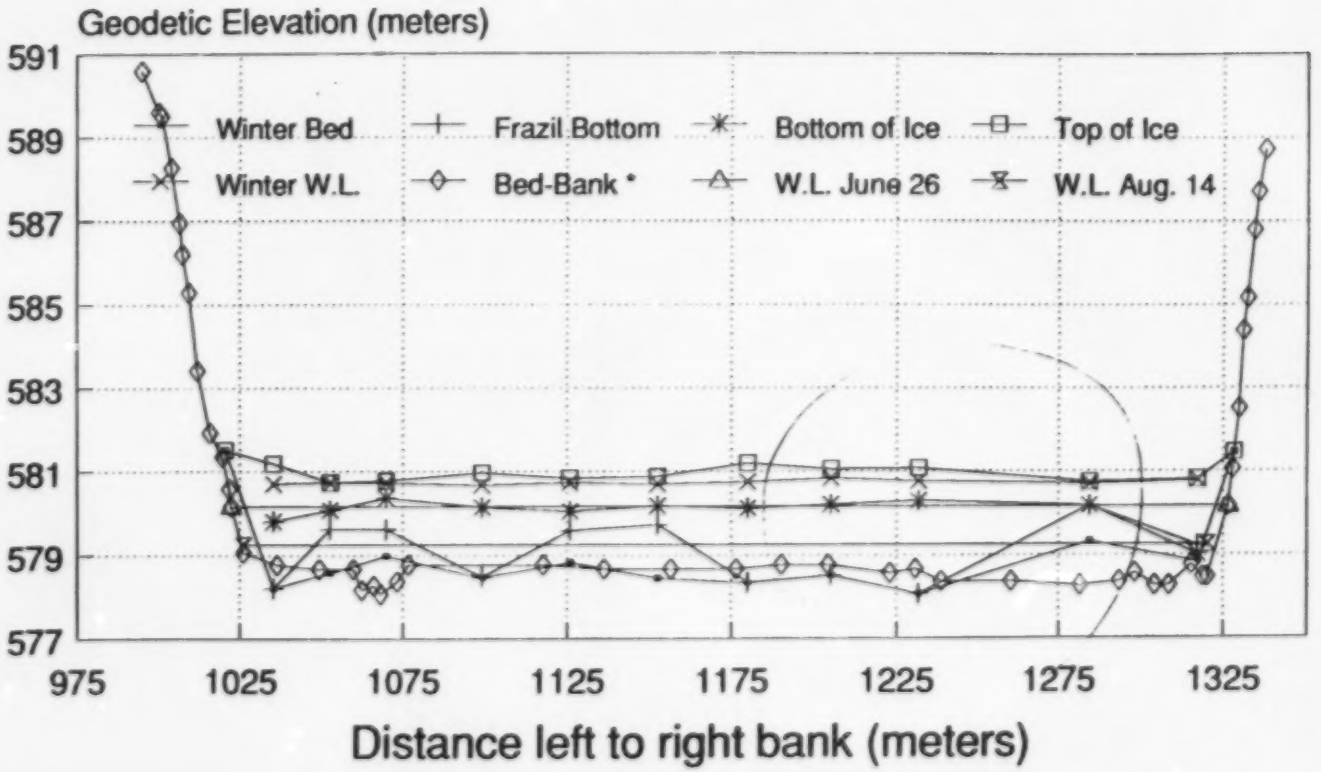


Hamilton & Olsen (Jan. 23)
Alberta Environment (summer)
*Bed & Bank survey June 26

NORTH SASKATCHEWAN RIVER

km. 745.0 (Bendermere Place)

1990 Winter & Summer Surveys

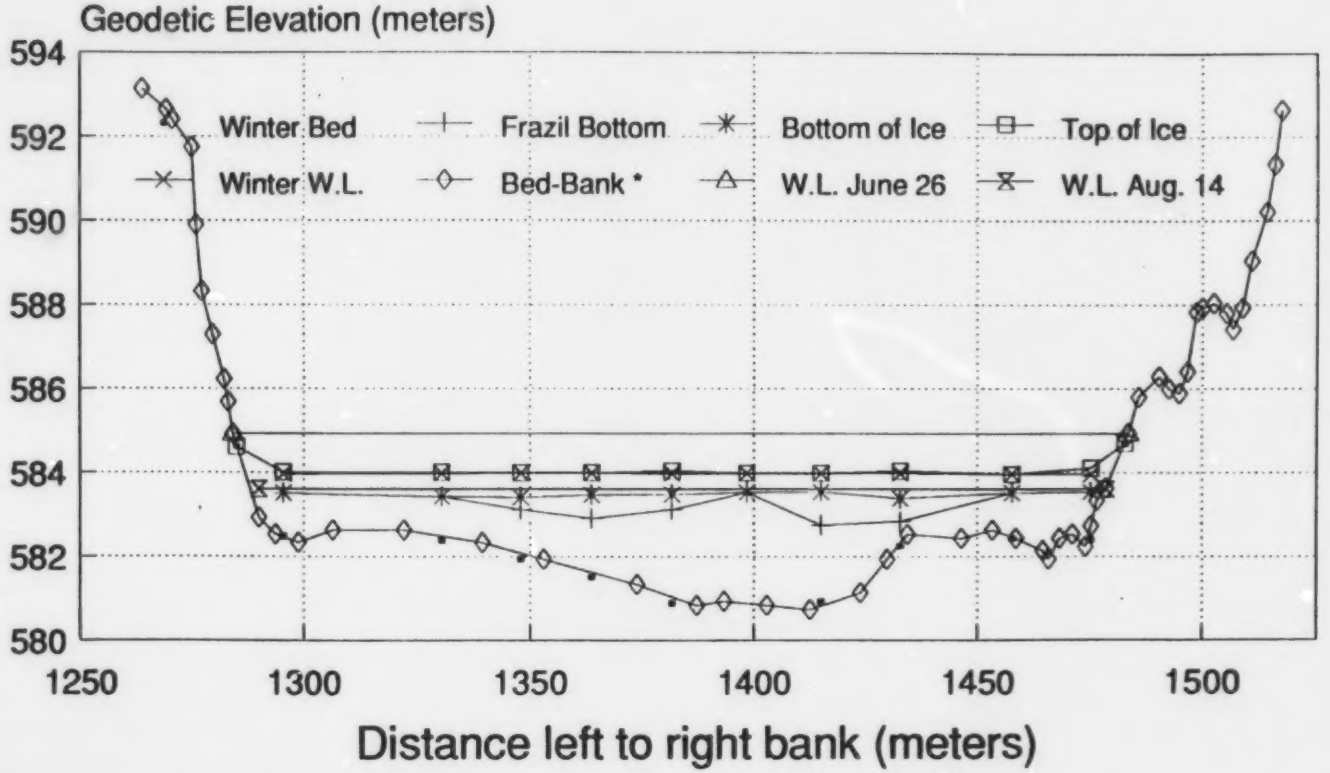


Hamilton & Olsen survey (Jan. 23)
Alberta Environment survey (summer)
AE bed & bank survey June 26

NORTH SASKATCHEWAN RIVER

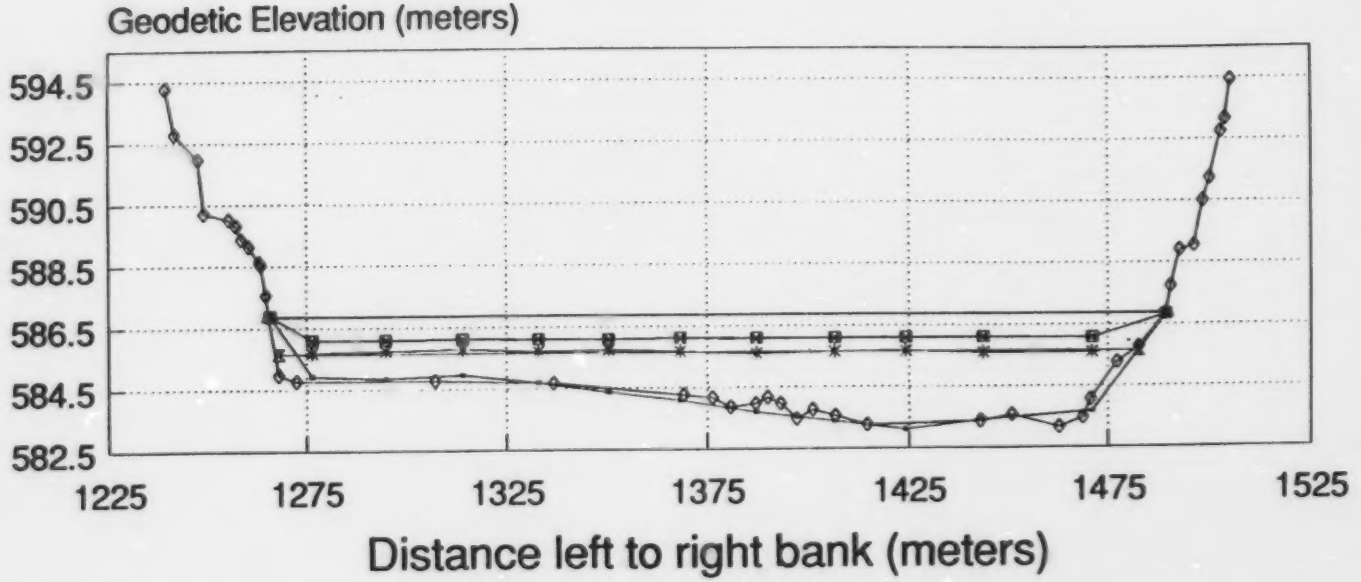
Km. 754.7 - Eldorena Ferry Site

1990 Winter & Summer Surveys



Hamilton & Olsen (Jan. 22)
Alberta Environment (Summer)
*Bed & Bank survey June 26

NORTH SASKATCHEWAN RIVER
Km. 761.4 - Just u/s of Sil Silica Plant
1990 Winter & Summer Surveys

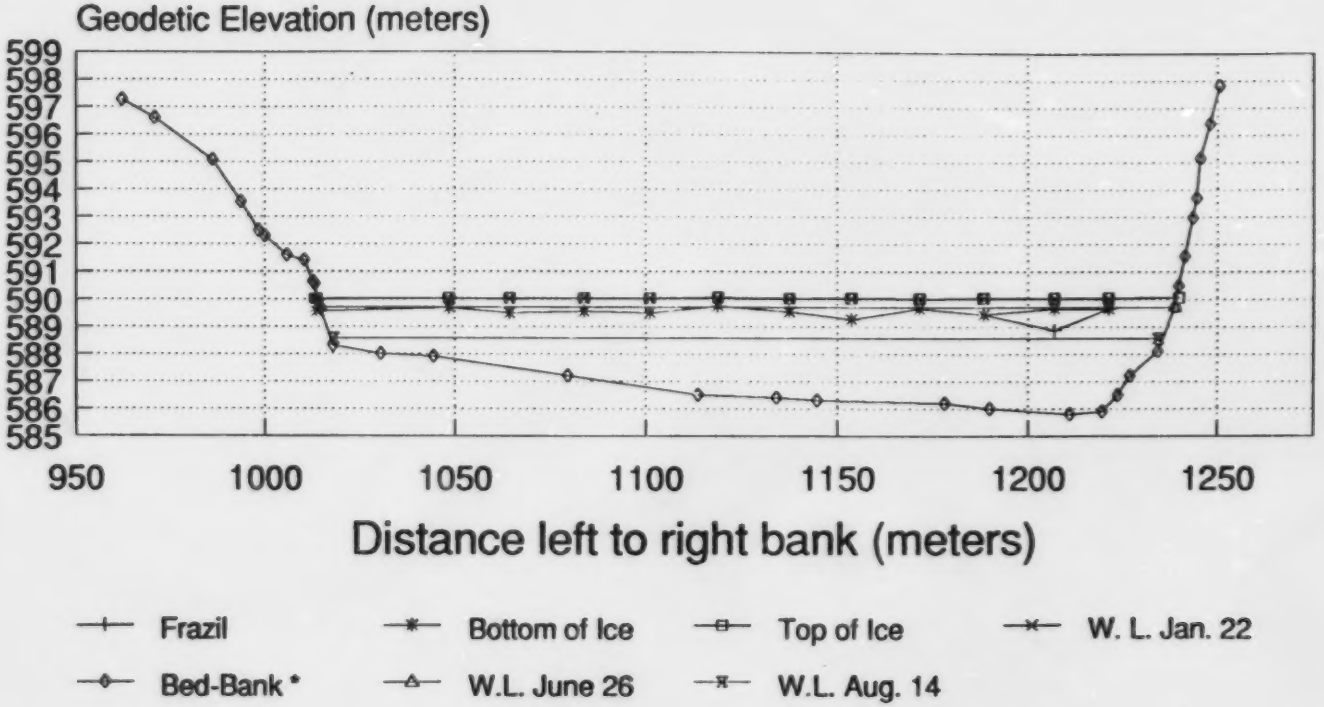


Hamilton & Olsen (Jan. 22)
Alberta Environment (summer)
* Bed & Bank survey June 26

NORTH SASKATCHEWAN RIVER

km. 764.6, 33 meters u/s of Vinca Bridge

1990 Winter & Summer Surveys

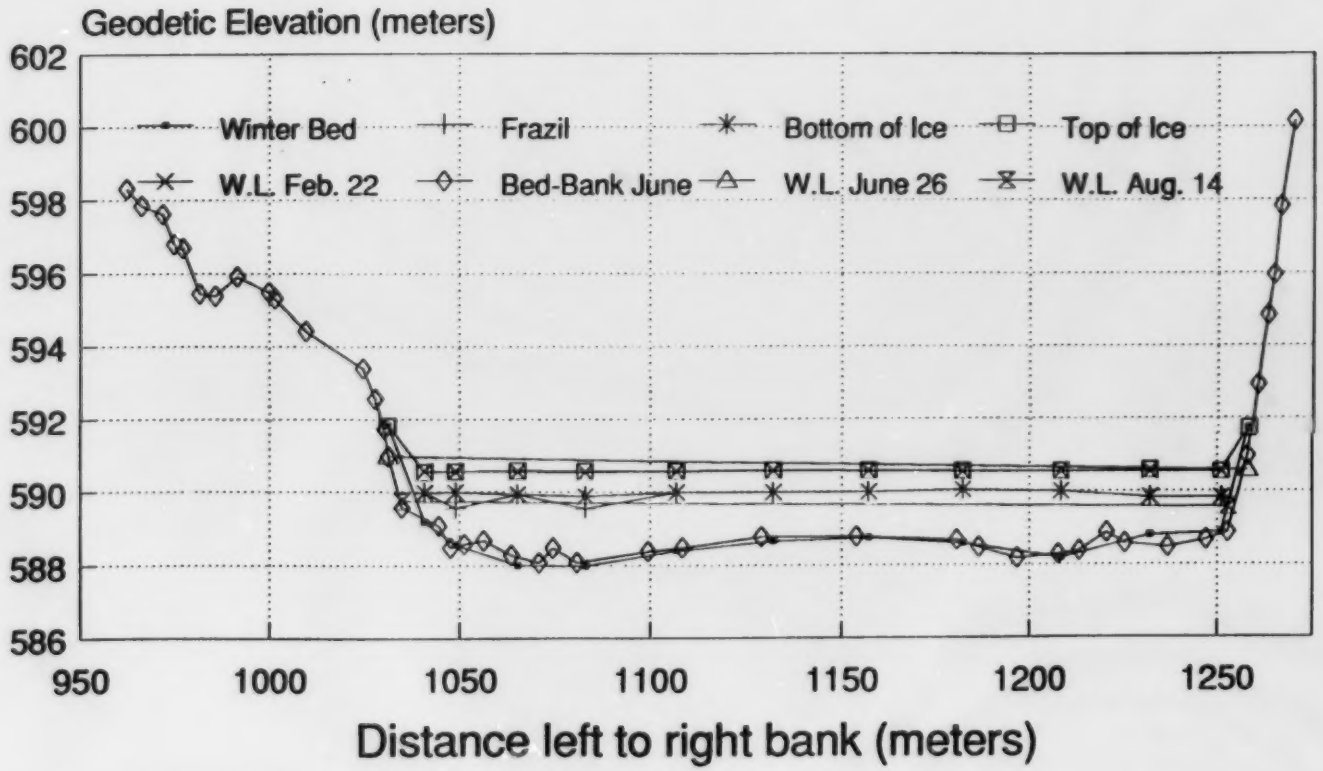


Hamilton & Olsen survey on Jan. 22
*Alberta Environment survey on June 26
for bed & bank. Profile survey Aug. 14

NORTH SASKATCHEWAN RIVER

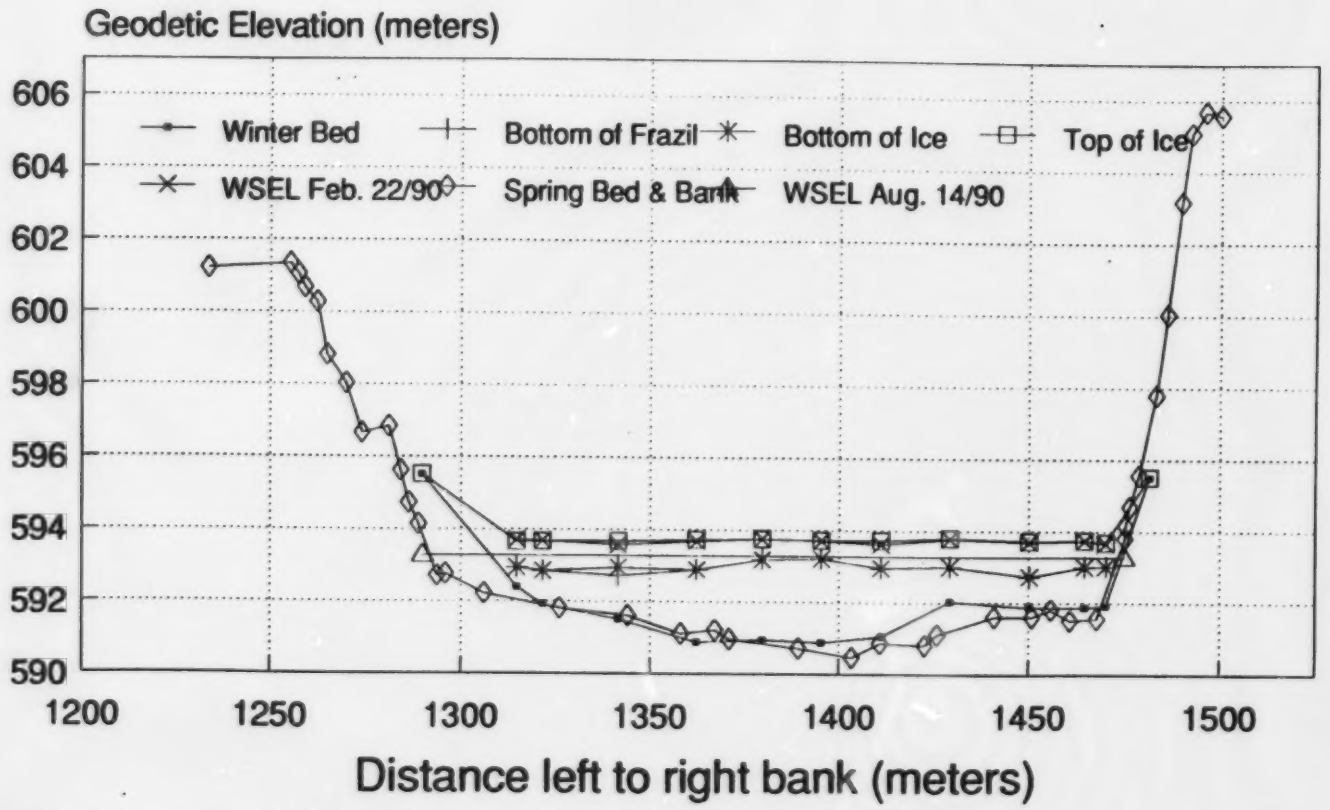
Km. 769.8, at oil co. pumphouse

1990 Winter & Summer Surveys



Hamilton & Olsen Survey Feb. 22
Alberta Environment Survey June 26
for Bed & Banks. Profile Aug. 14

NORTH SASKATCHEWAN RIVER
Km 778.37, 120 m. u/s of Shell Intake
1990 winter & 1986 spring surveys

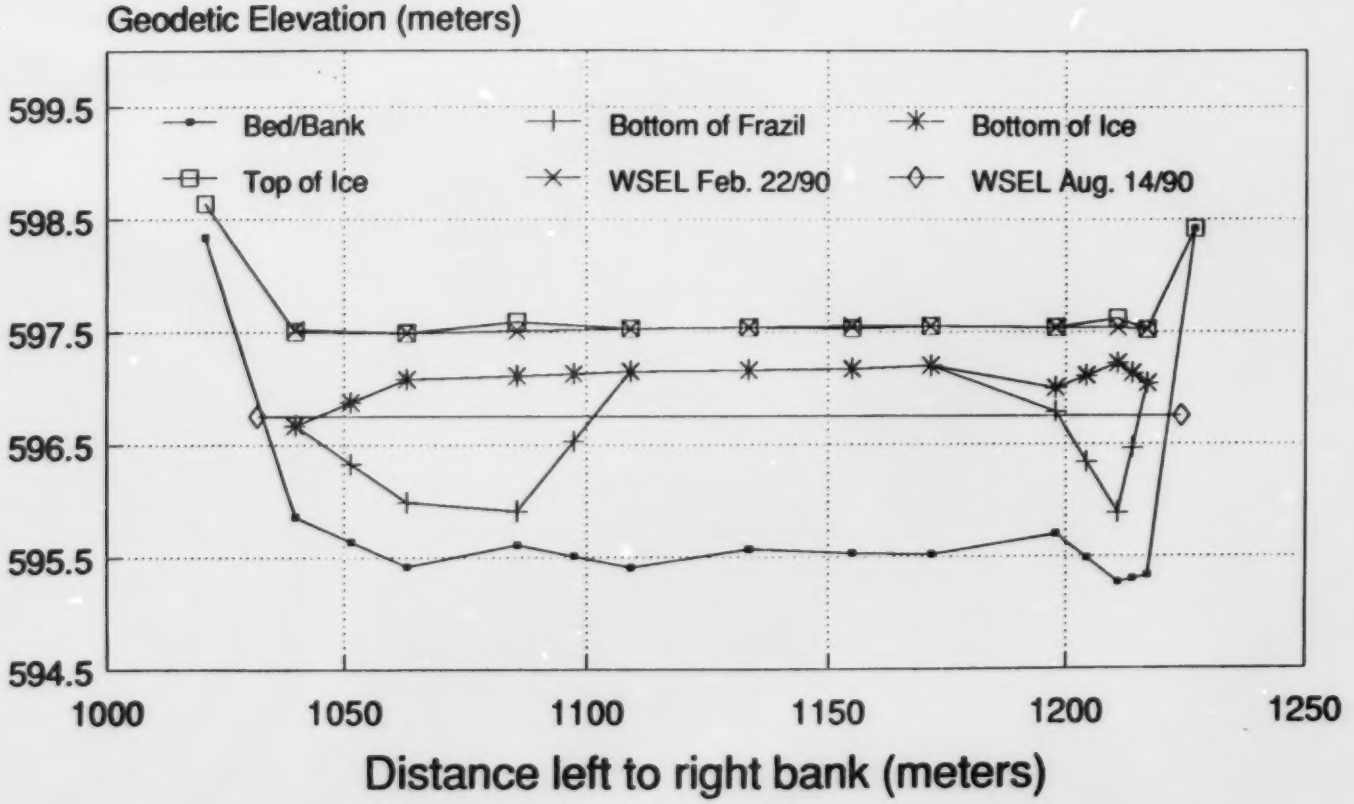


Hamilton & Olsen survey Feb 22
Alberta Environment survey May/June

NORTH SASKATCHEWAN RIVER

Km. 786.8 (5-D), Farm w/orchard dr.

1990 Winter & Summer Surveys

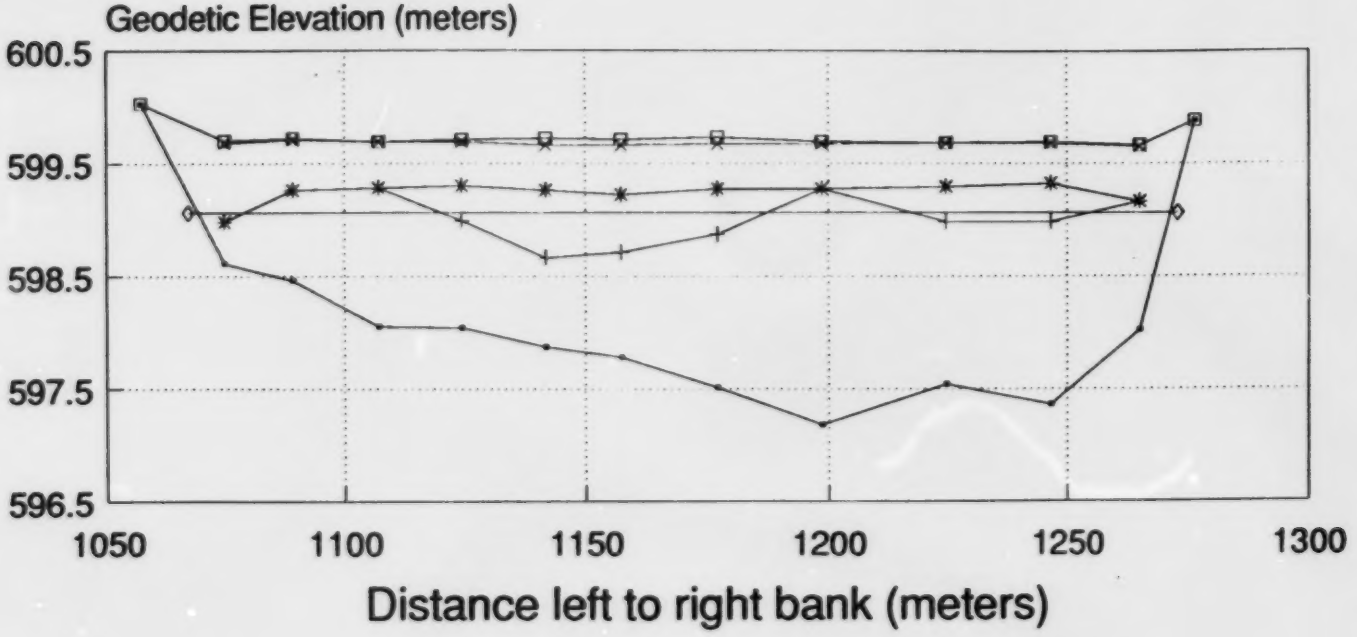


2 chaotic ice surfaces: 1047.8-
1093.8 & 1178.9-1197.8 meters.

NORTH SASKATCHEWAN RIVER

Km.791.95 Ft. Sask. Ferry site

1990 Winter & Summer Surveys

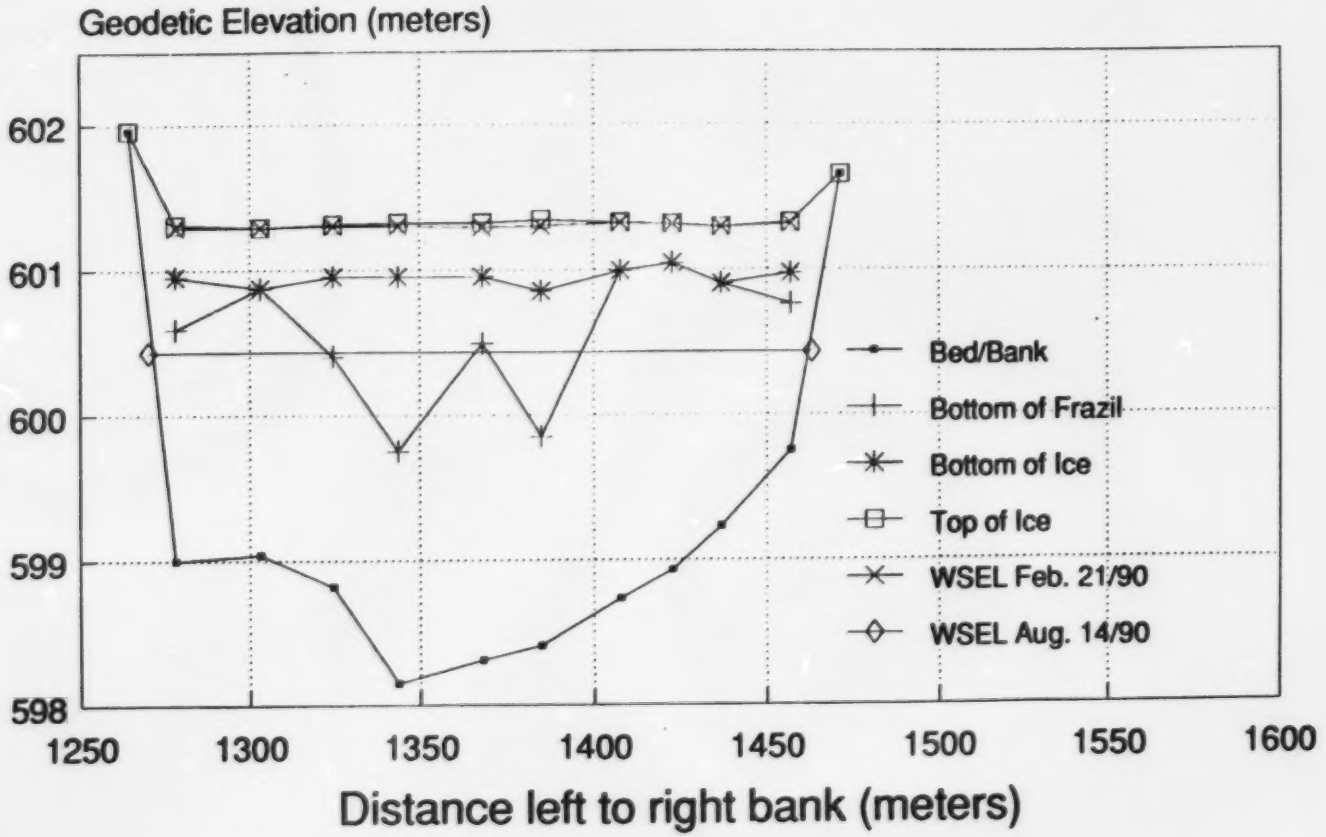


Right side of bar, i.e right channel.

NORTH SASKATCHEWAN RIVER

Km. 795.55 (2-D)

1990 Winter & Summer Surveys

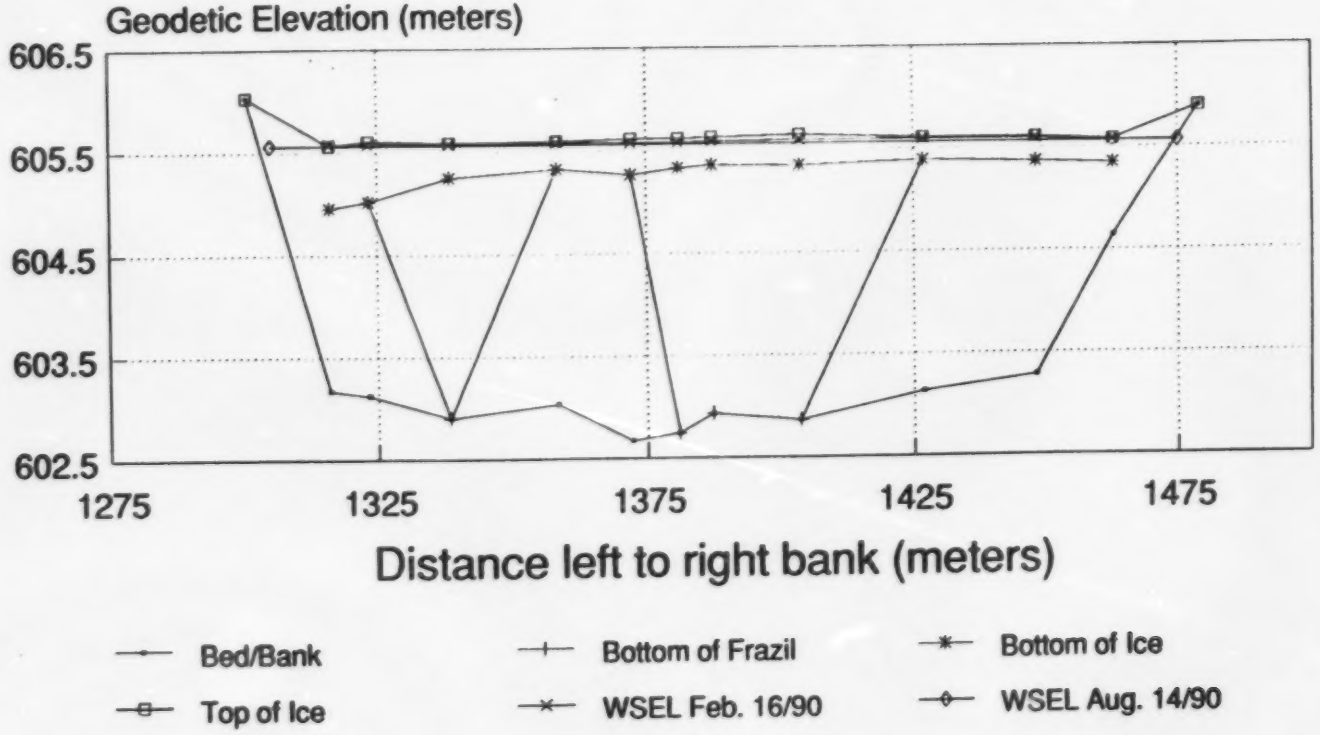


2 m. u/s of small creek LB.

NORTH SASKATCHEWAN RIVER (86-NS-11.46)

Km. 807.08-Capital City Regional Sewage

1990 Winter & Summer Surveys

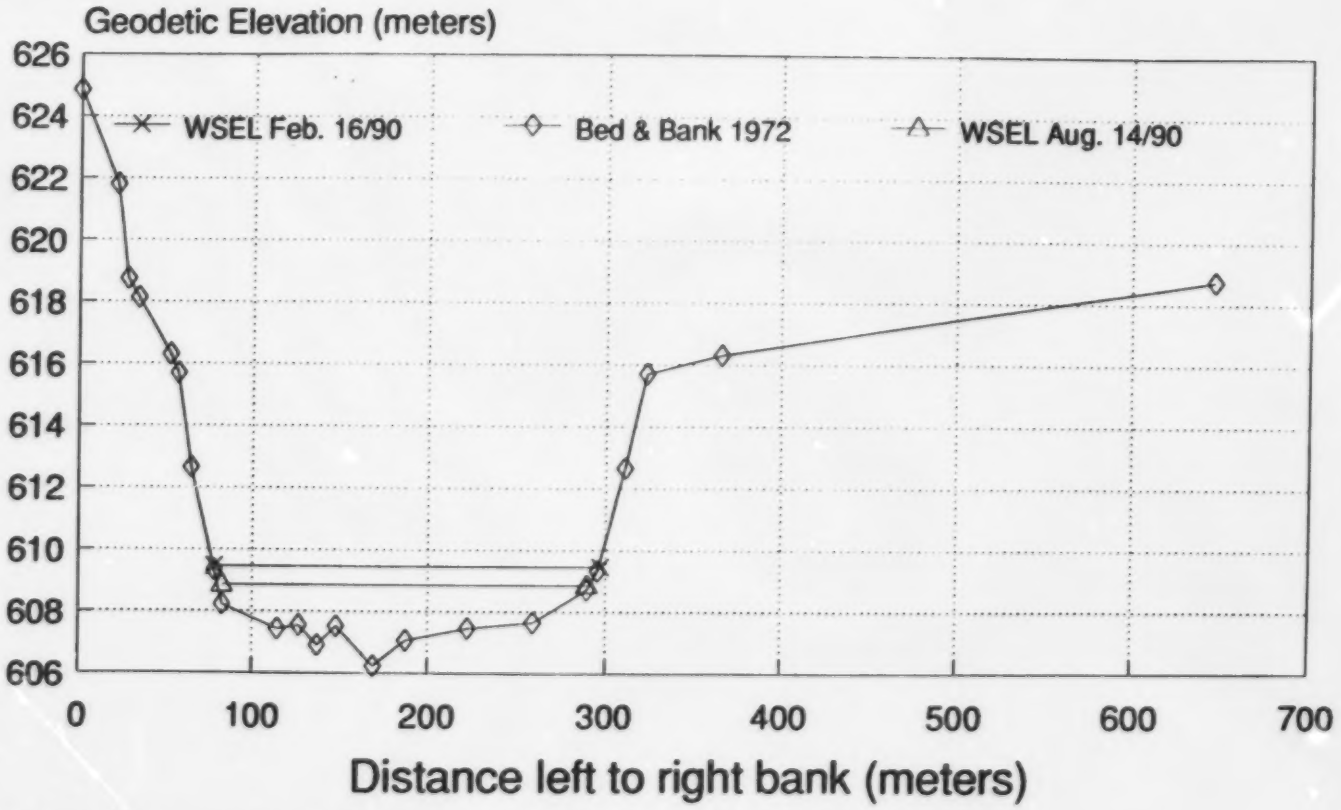


Match up with 1972 section @ 807.31
Shear @ 1313, 1337, 1382 and 1471 meters

NORTH SASKATCHEWAN RIVER

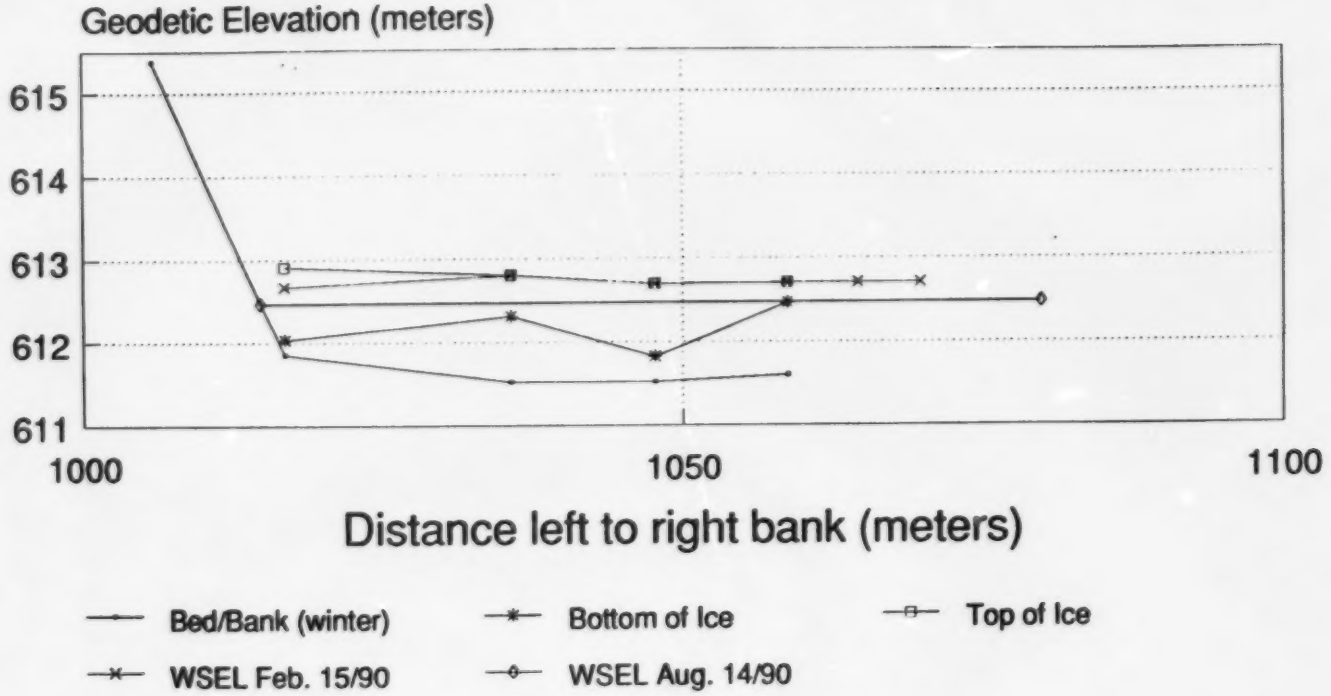
Km. 815.8, by TBG Gravel Pit

1990 & 1972 surveys.



Ham. & Olsen (Feb 16/90). AE (1972)
No ice survey 1990 (50% ice-1 cm. thick)

NORTH SASKATCHEWAN RIVER
km. 828.79 @ 87 St. & 101A Ave
1990 Winter & Summer Surveys.

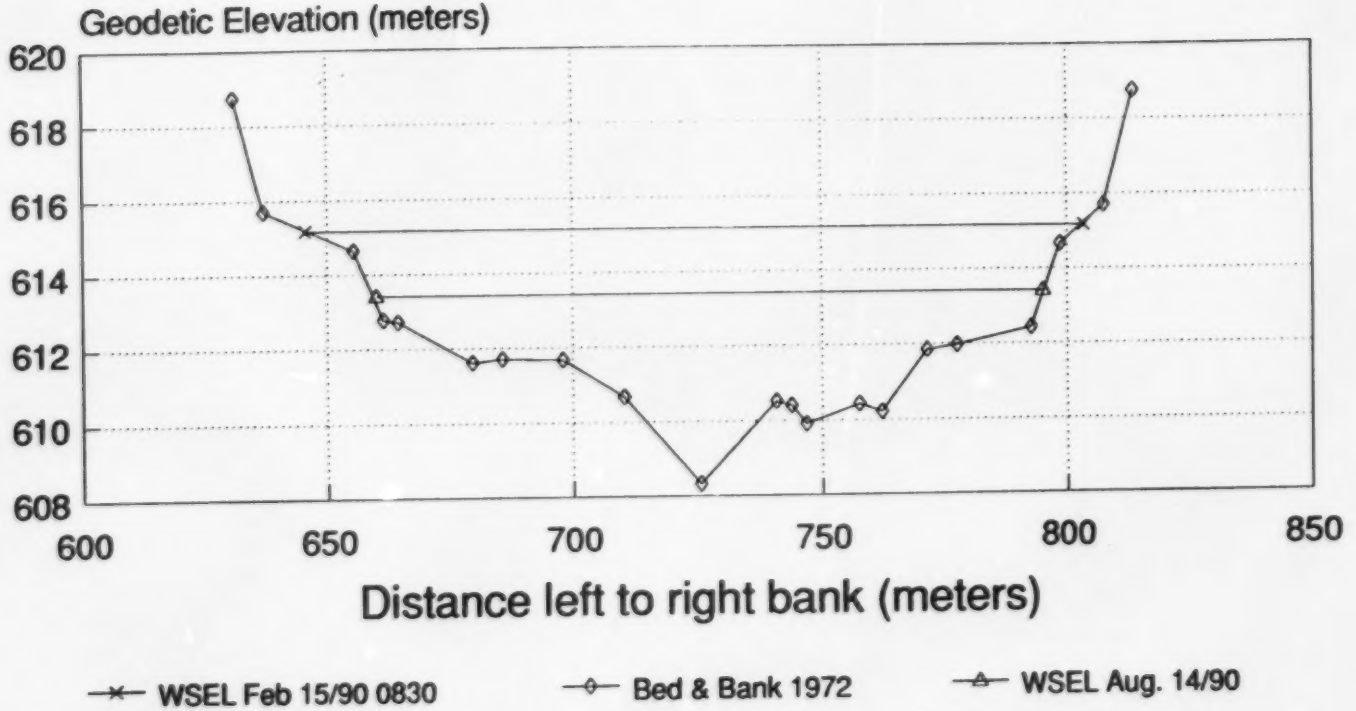


Level hole locations generally surrounded by approx. 1.5 meter high shoved ice.

NORTH SASKATCHEWAN RIVER

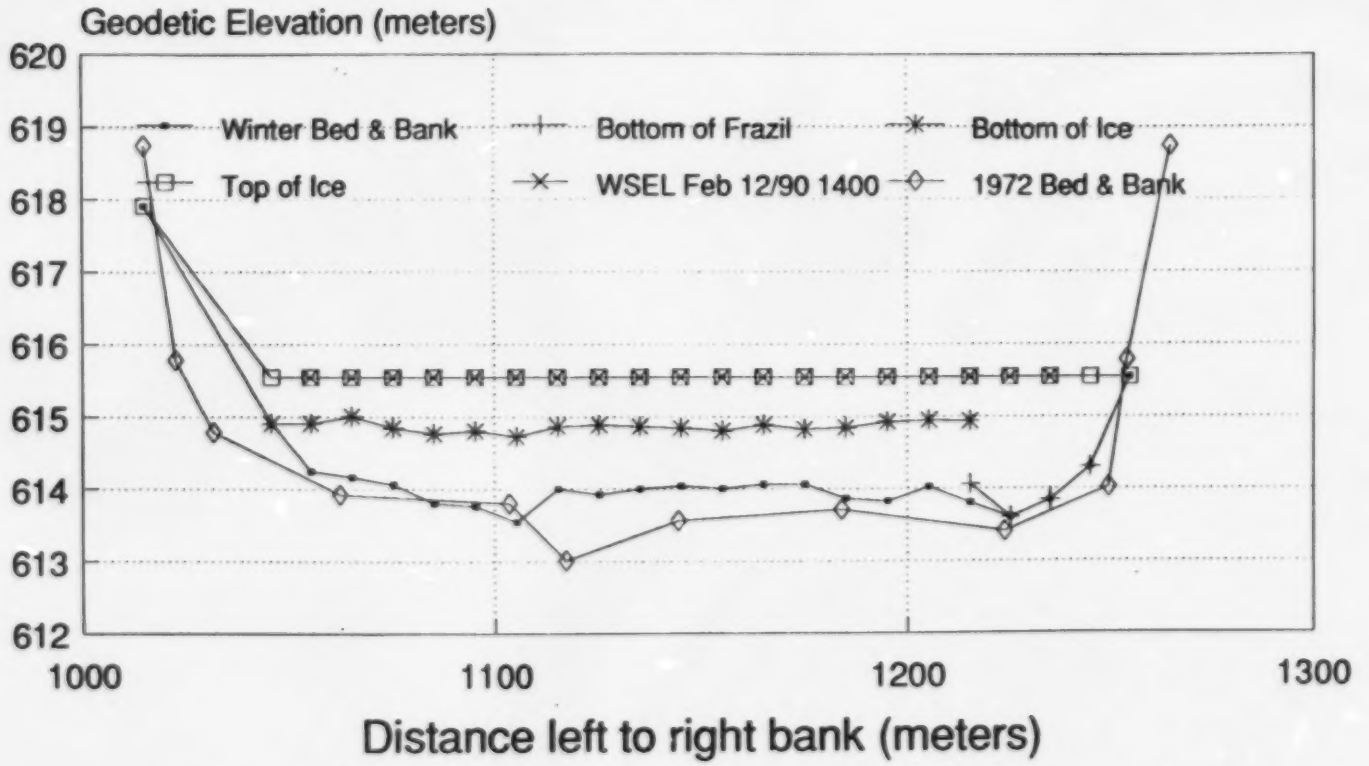
Km. 831.99, u/s James MacDonald Bridge

1990 Winter and 1972 Summer Survey



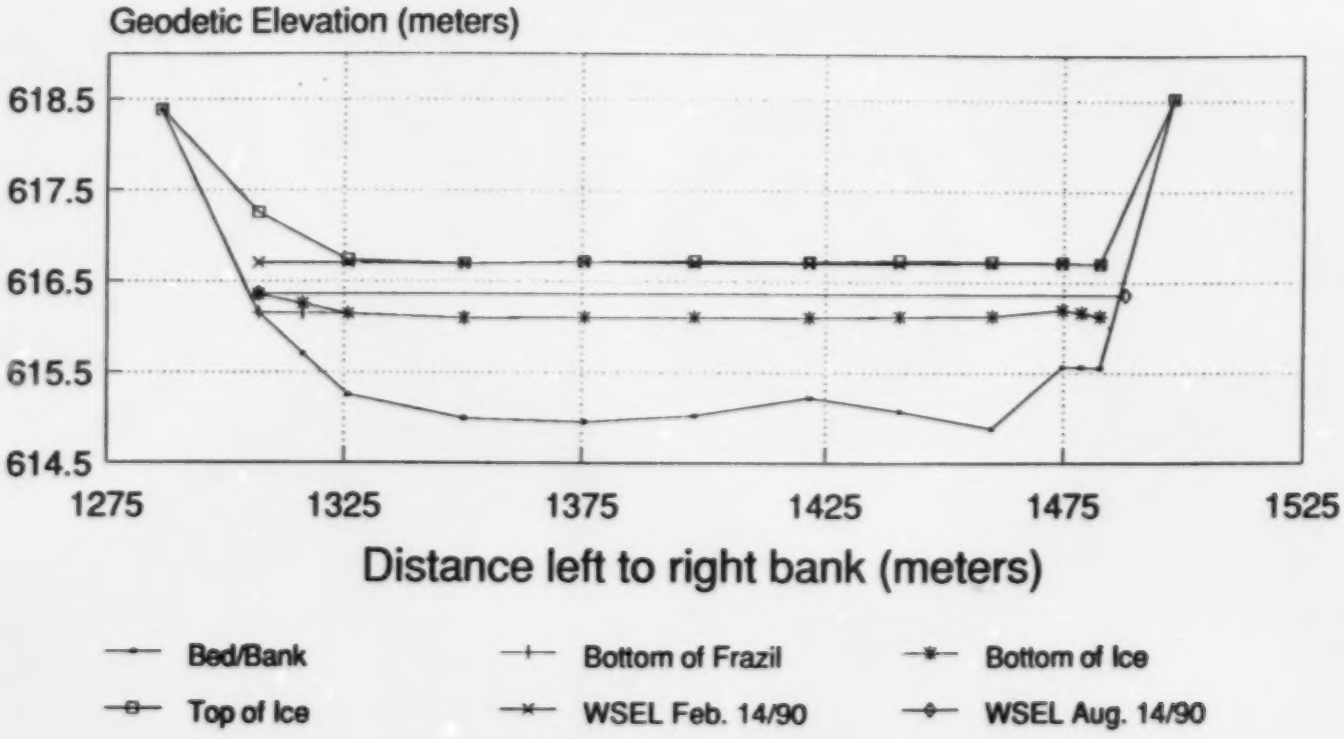
Water level interpolated from Km. 831.80 using S=.00014 (from data compiled to 1988). Right half of river ice covered.

NORTH SASKATCHEWAN RIVER
Km. 834.9-opposite Bio. Sc. U.A.
1990 Winter & 1972 Summer Surveys



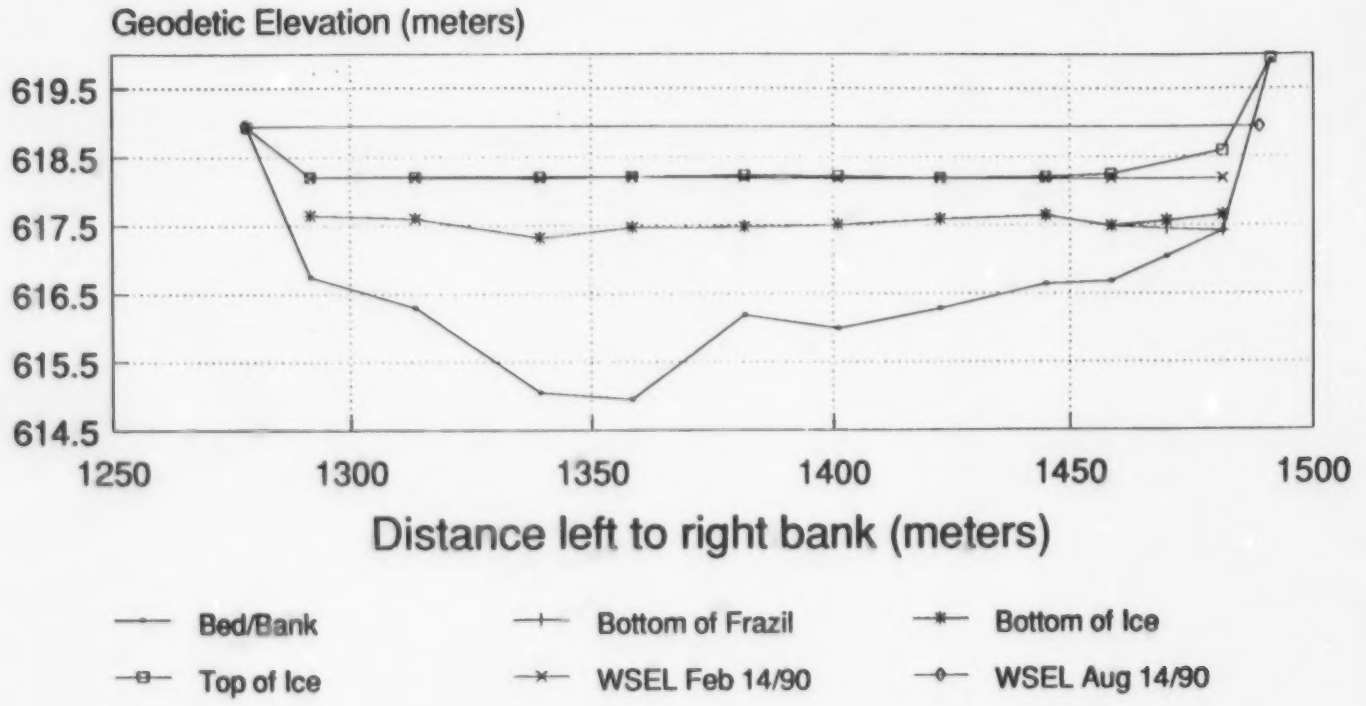
WSC ice info. No info. on top of ice-assume top of ice and water level coincide. See notes on Lotus output.

NORTH SASKATCHEWAN RIVER
km. 838.25 Hawrelak Park @ fenced intake
1990 Winter & Summer Surveys



Shear lines @ 1301.1 & 1319.2 meters.
Match with 1972 sect. @ 831.40

NORTH SASKATCHEWAN RIVER
km. 841.85 u/s Quesnell Br.
1990 Winter & Summer Surveys



Shear lines @ 1470.2 and 1480.1 m.
Generally smooth ice surface.
NO MATCH WITH 1972 SURVEY

REGRESSION ANALYSIS REACH A1
-FULL ICE COVER-
KM. 0.0-17.3 (849.3-831.99)

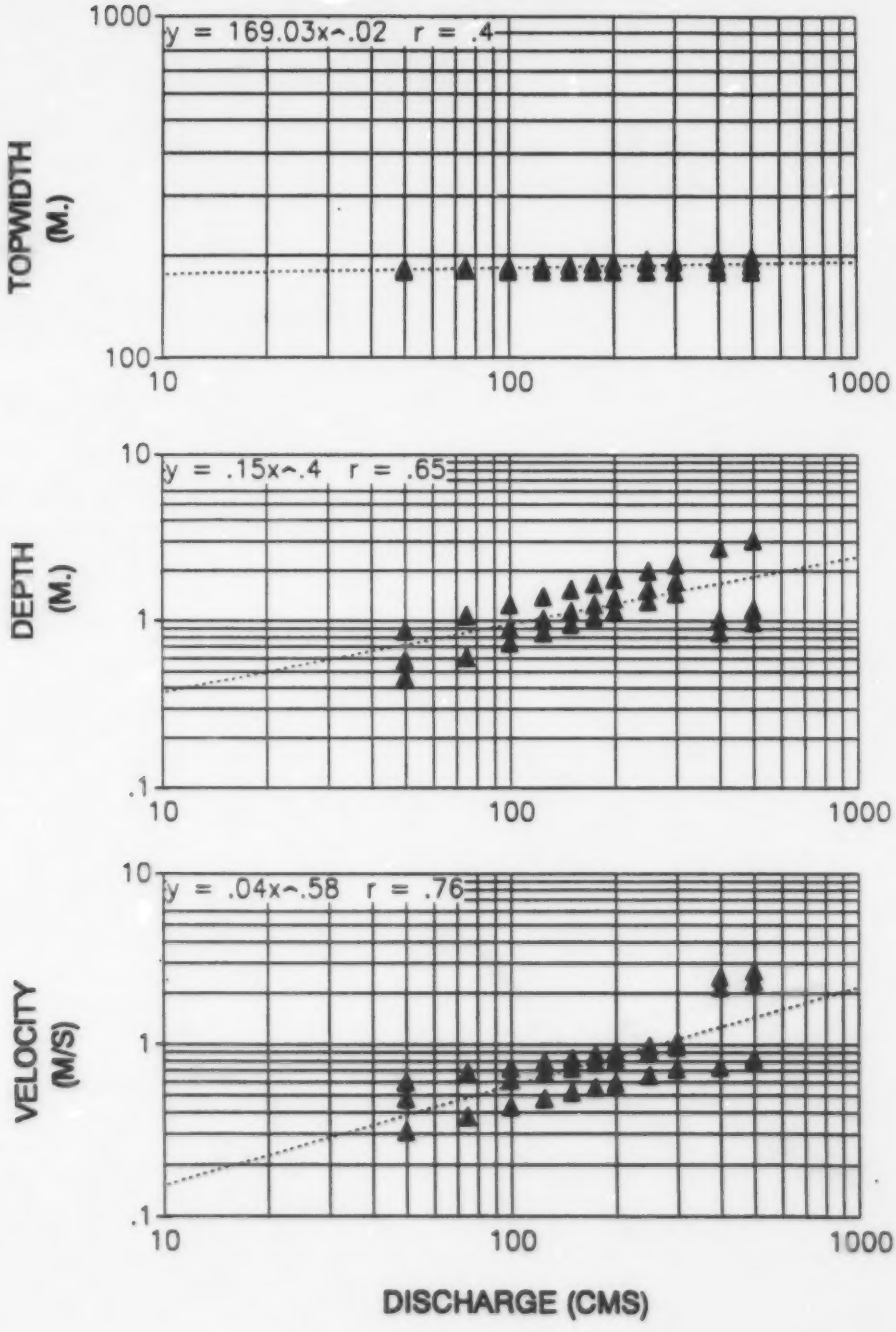


FIG. 4A.1

Regression analysis Reach A2
-Partial Ice Cover-
Km. 17.3-33.8 (831.99-815.79)

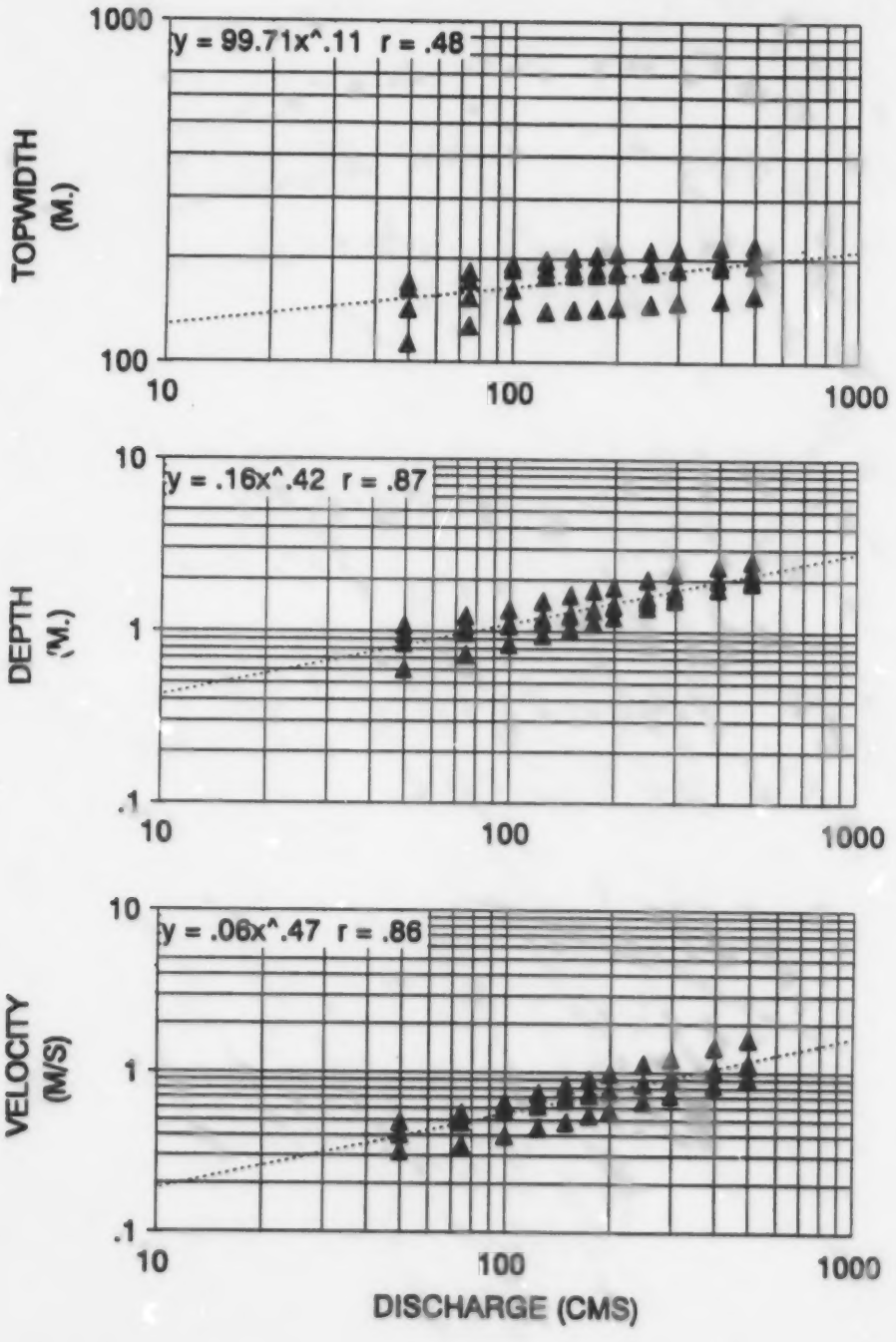


FIG. 4A.2

Regression analysis Reach A 3
-Full Ice Cover-
Km. 33.8-59.4 (815.79-789.9)

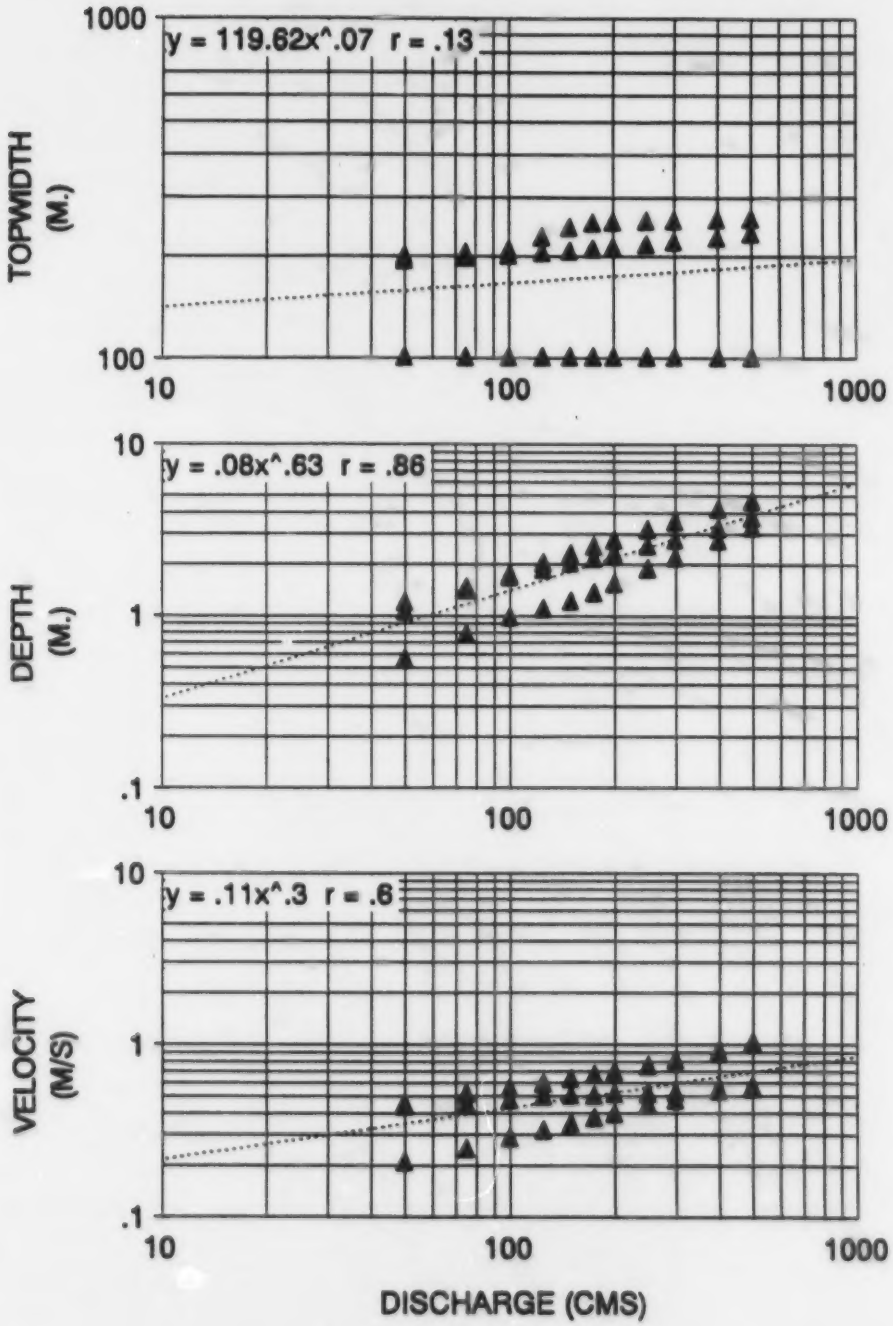


FIG. 4A.3

Regression Analysis Reach A
-Open Water-
Km. 0.0-59.4 (849.3-789.9)_

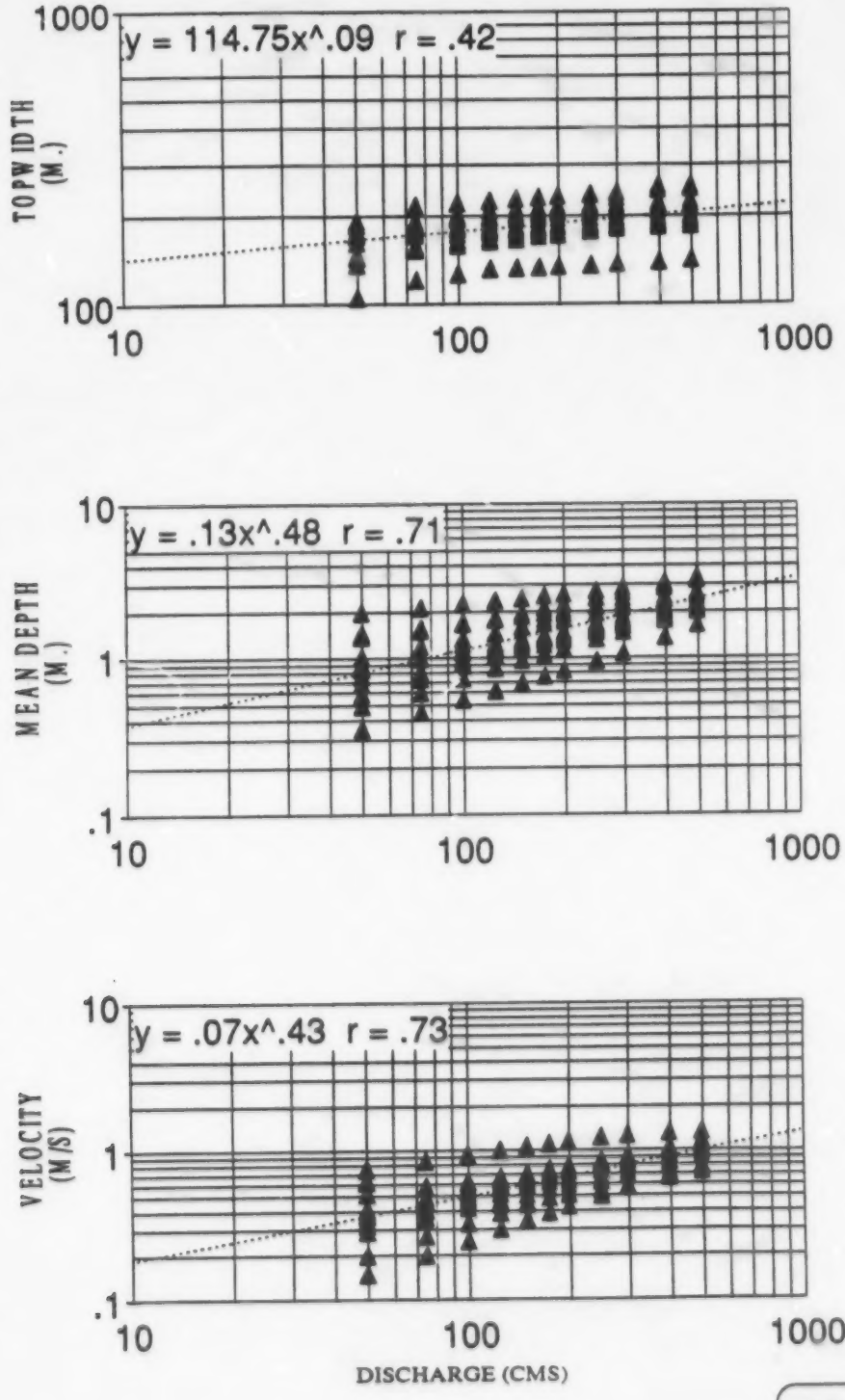


FIG. 4B

Regression analysis Reach B
-Ice Covered-
Km. 59.4-85.4 (789.9-763.9)

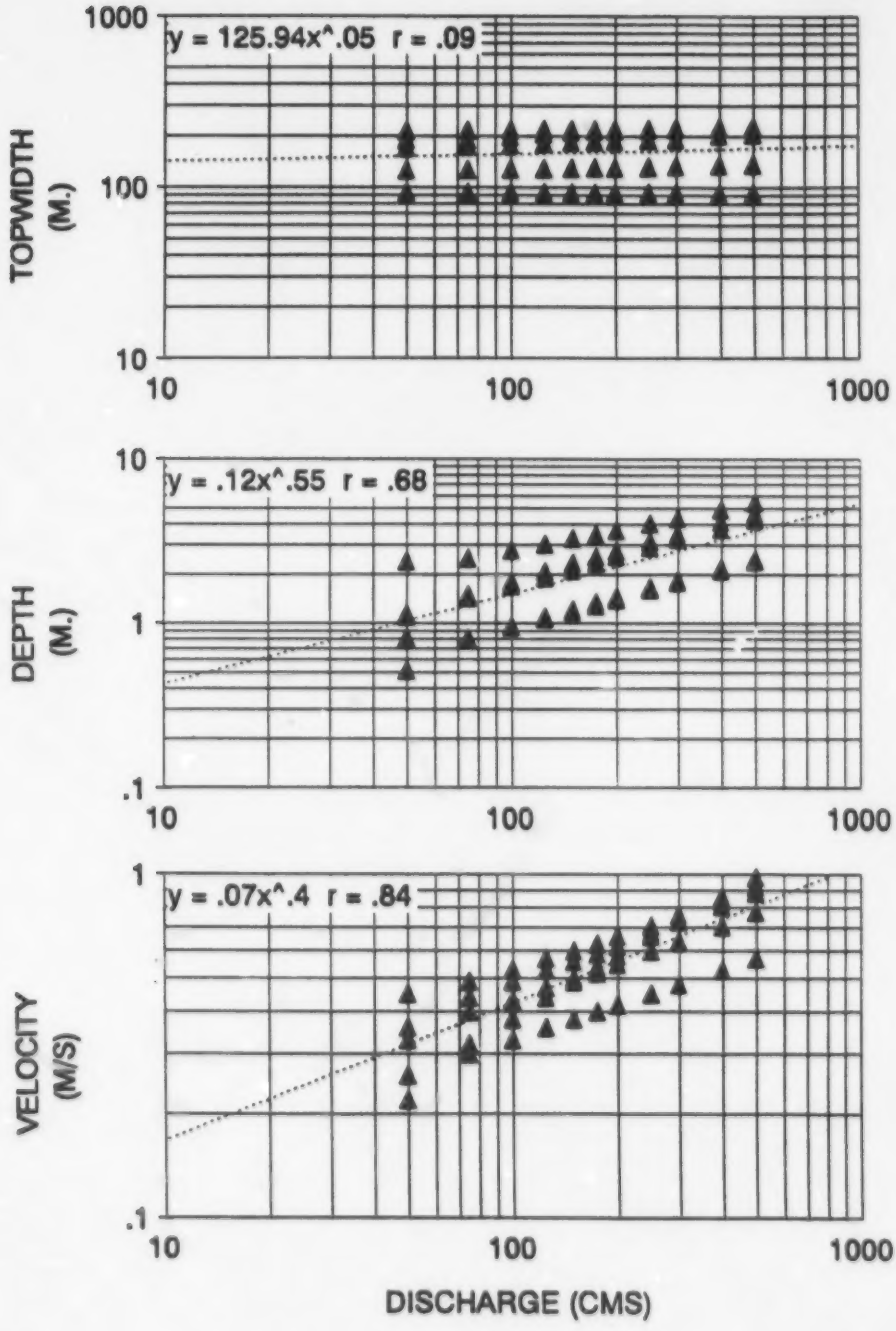


FIG. 5A

Regression Analysis Reach B
-Open Water-
Km. 59.4-85.4 (789.9-763.9)

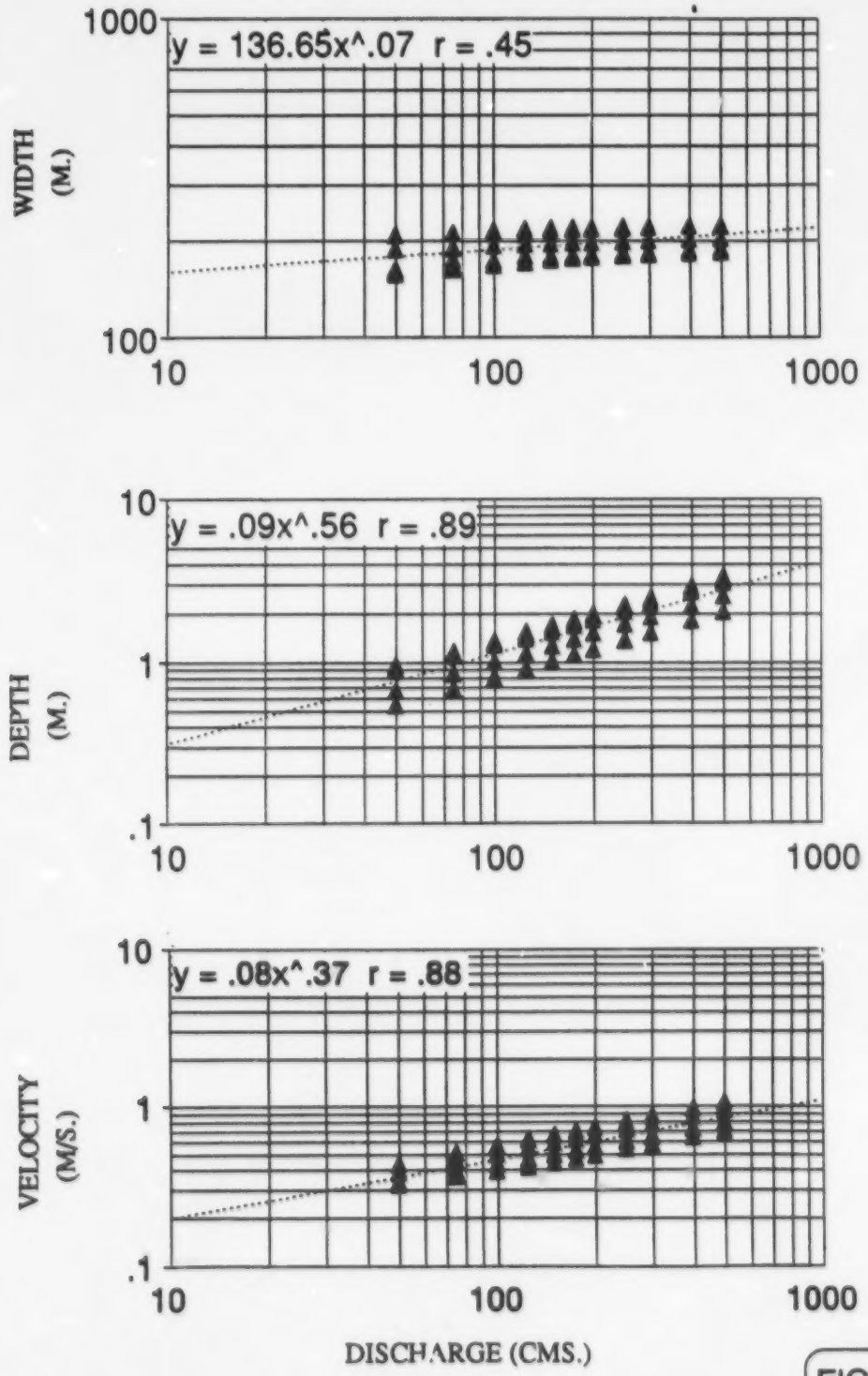


FIG. 5B

Regression Analysis Reach C
-Ice Covered-
Km. 85.4-117.8 (763.9-731.5)

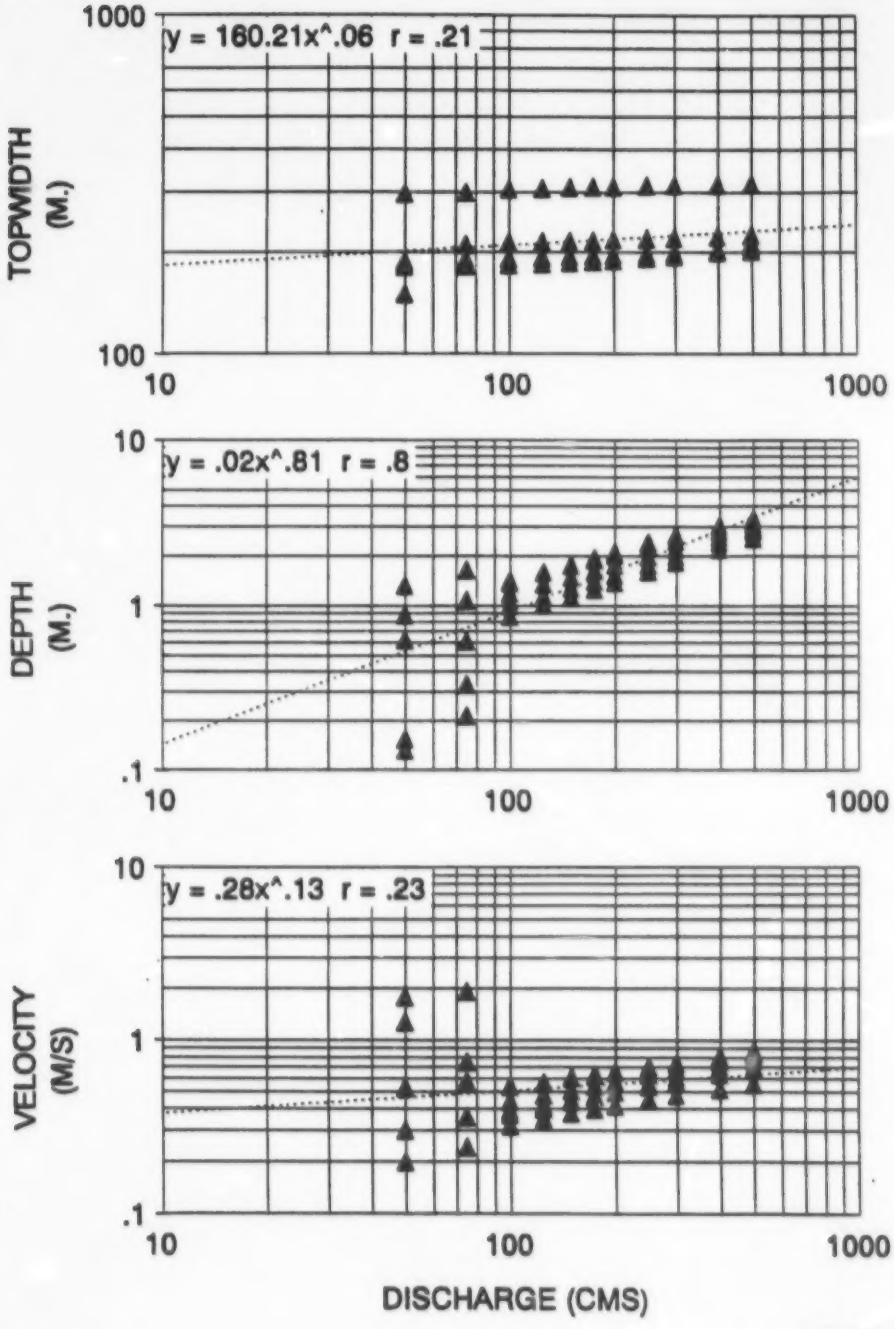


FIG. 6A

Regresssion Analysis Reach C
-Open Water-
Km. 85.4-117.8 (763.9-731.5)

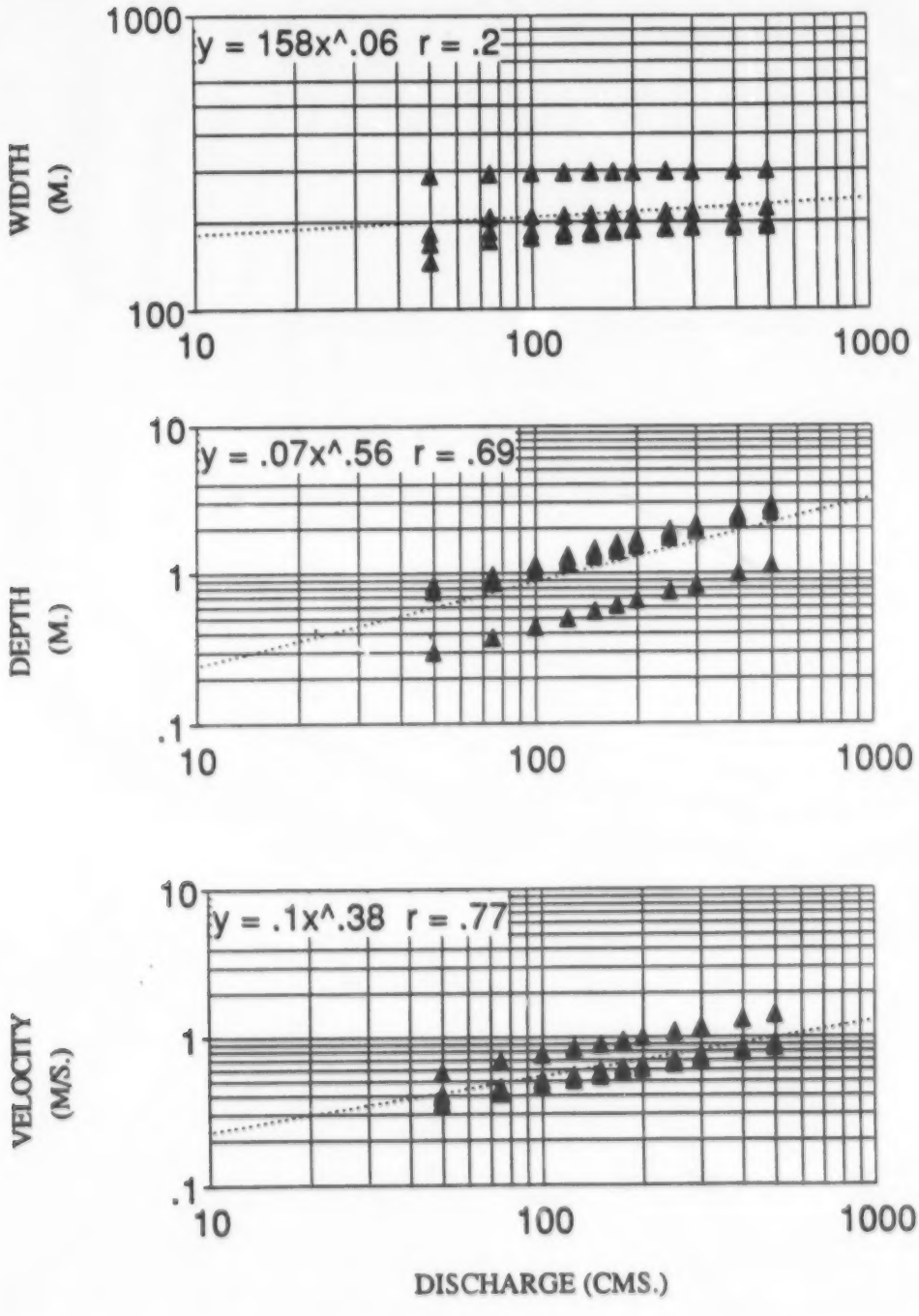


FIG. 6B

Regression Analysis Reach D
-Ice Covered-
Km. 117.8-174.8 (731.5-674.5)

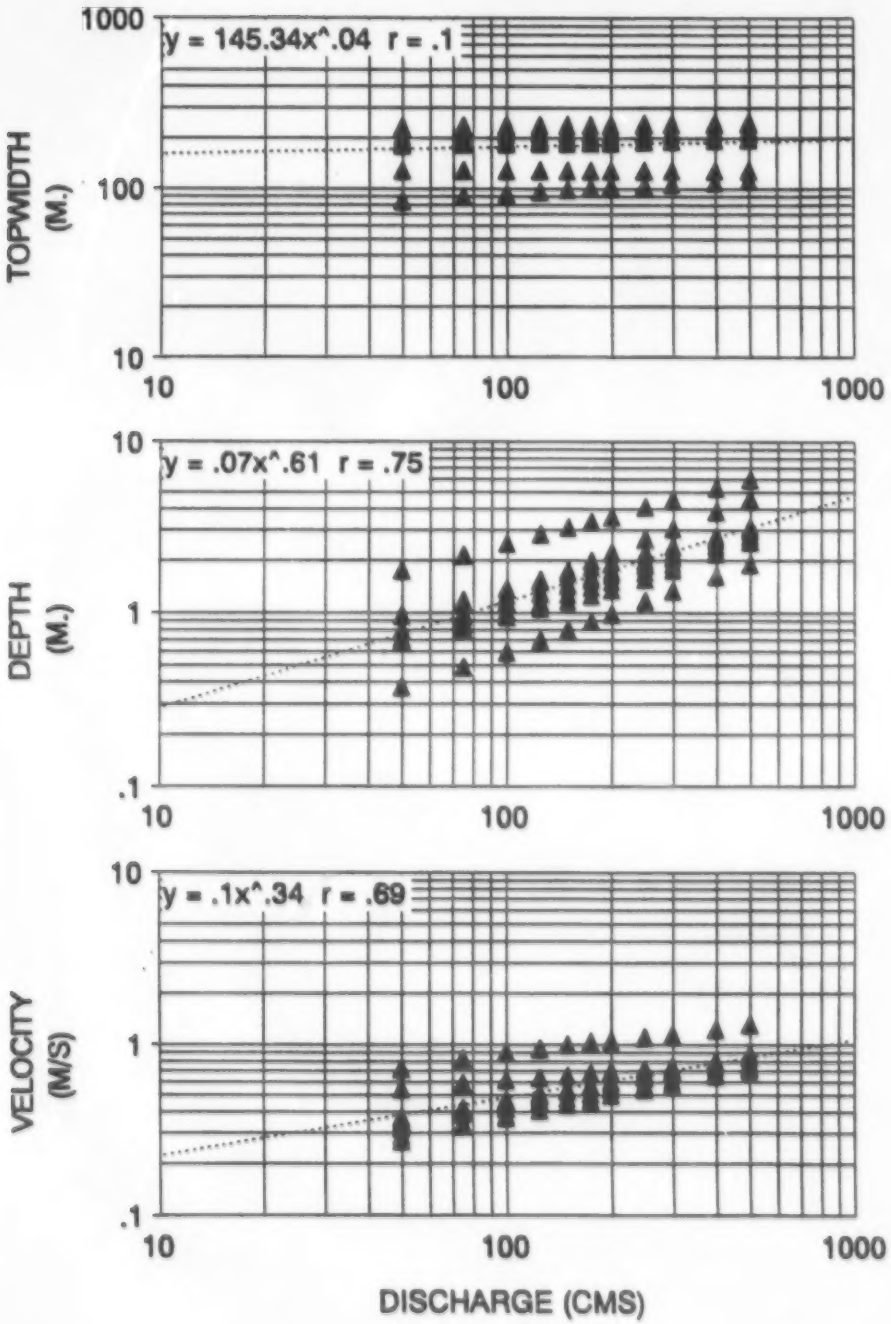


FIG. 7A

Regression Analysis Reach D
-Open Water-
Km. 117.8-174.8 (731.5-674.5)

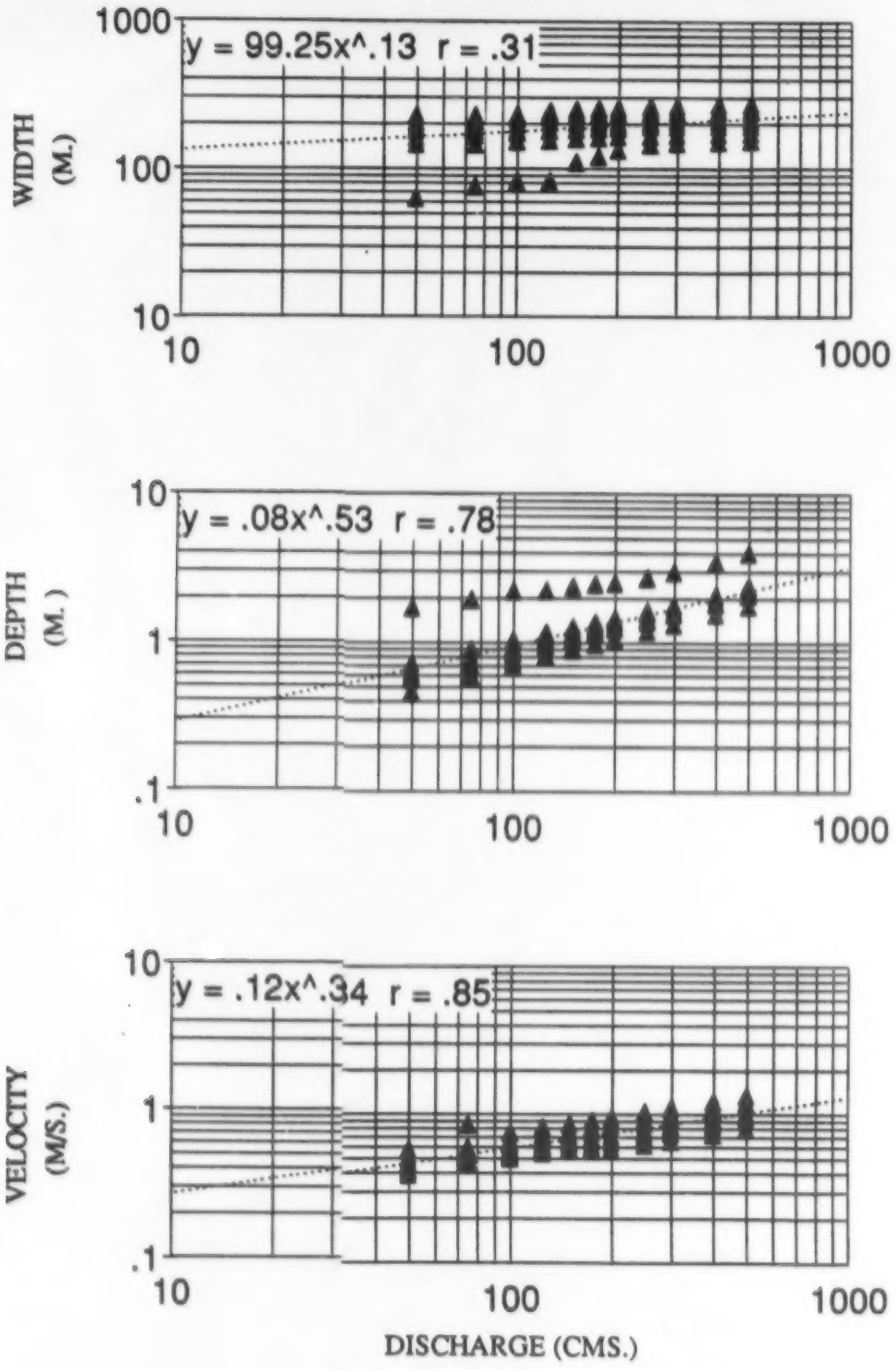


FIG. 7B

Regression Analysis Reach E
-Full Ice Cover-
Km. 174.8-222.0 (674.5-627.3)

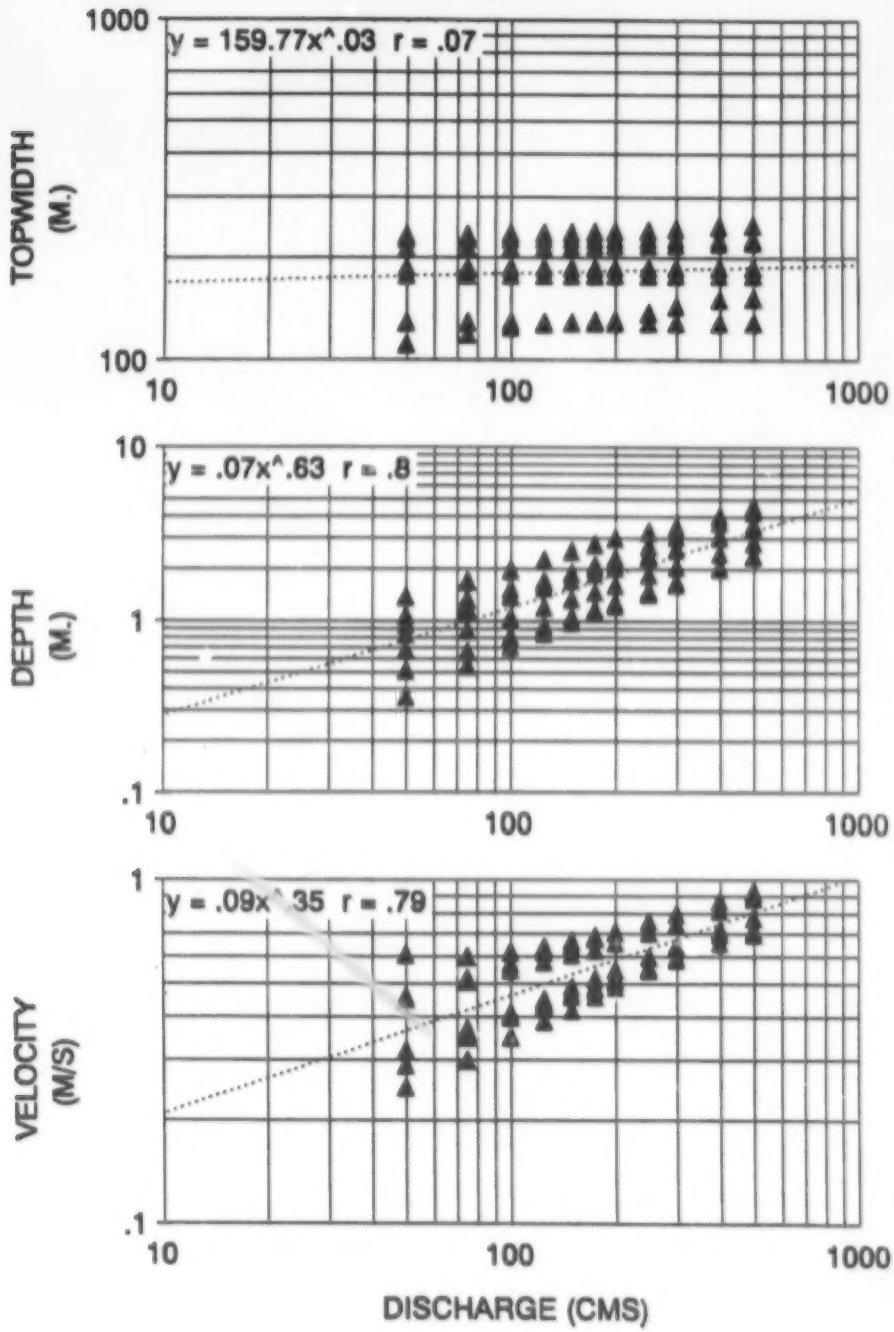


FIG. 8A

Regression Analysis Reach E
-Open Water-
Km. 174.8-222.0 (674.5-627.30)

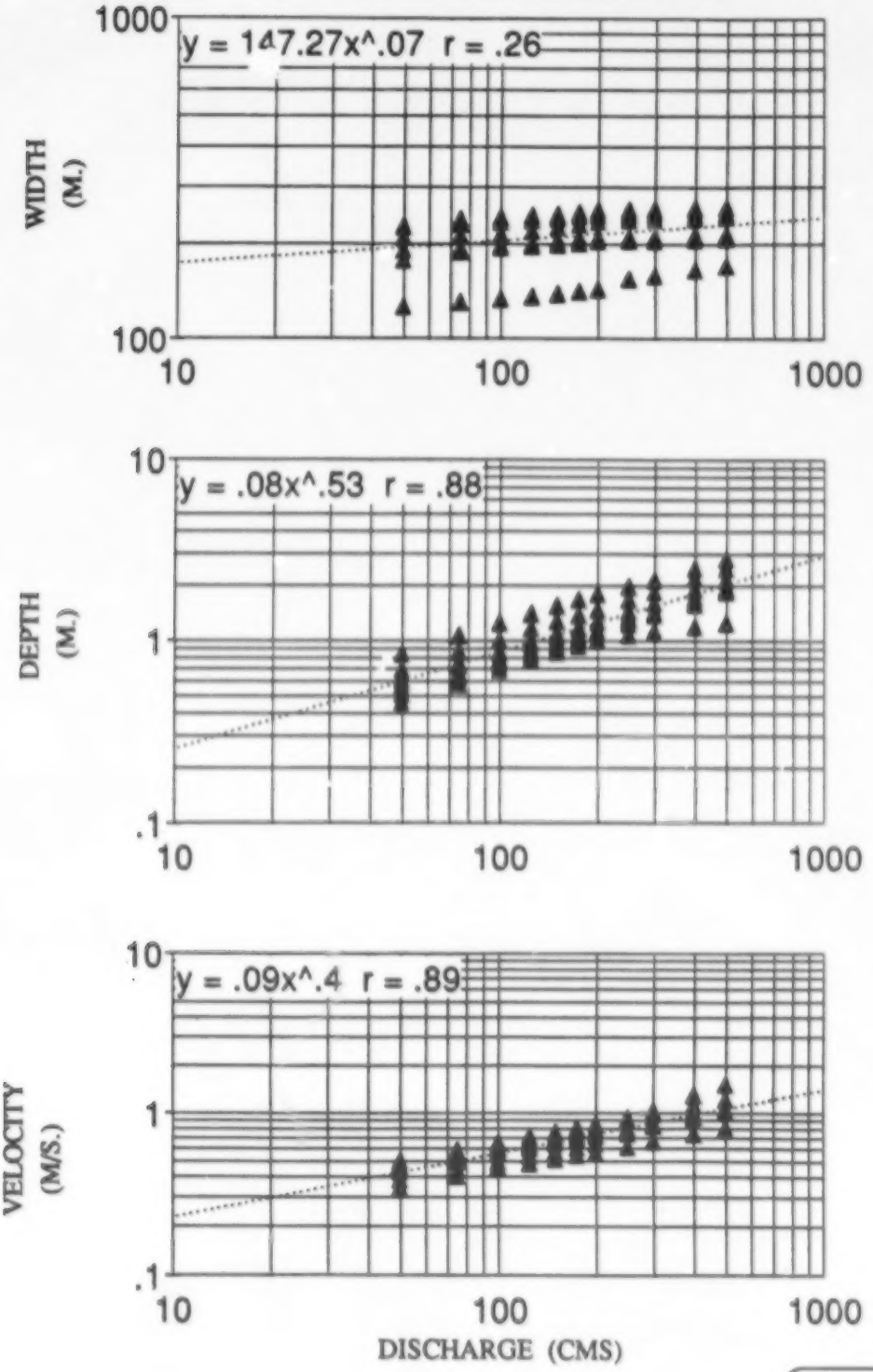


FIG. 8B

Regression Analysis Reach F
-Full Ice Cover-
Km. 222.0-262.0 (627.3-587.3)

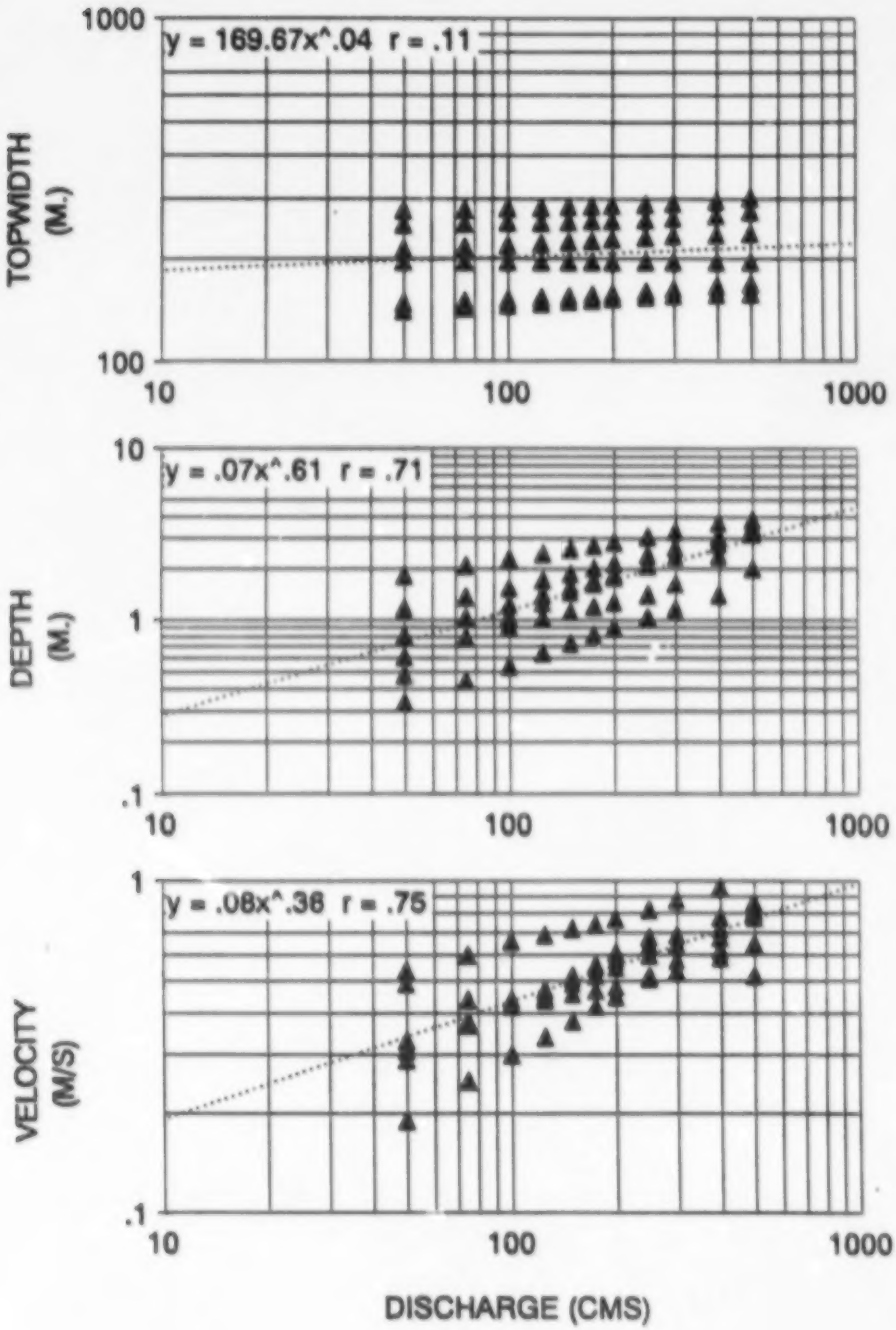


FIG. 9A

Regression Analysis Reach F
-Open Water-
Km. 222.0-262.0 (627.3-587.3)

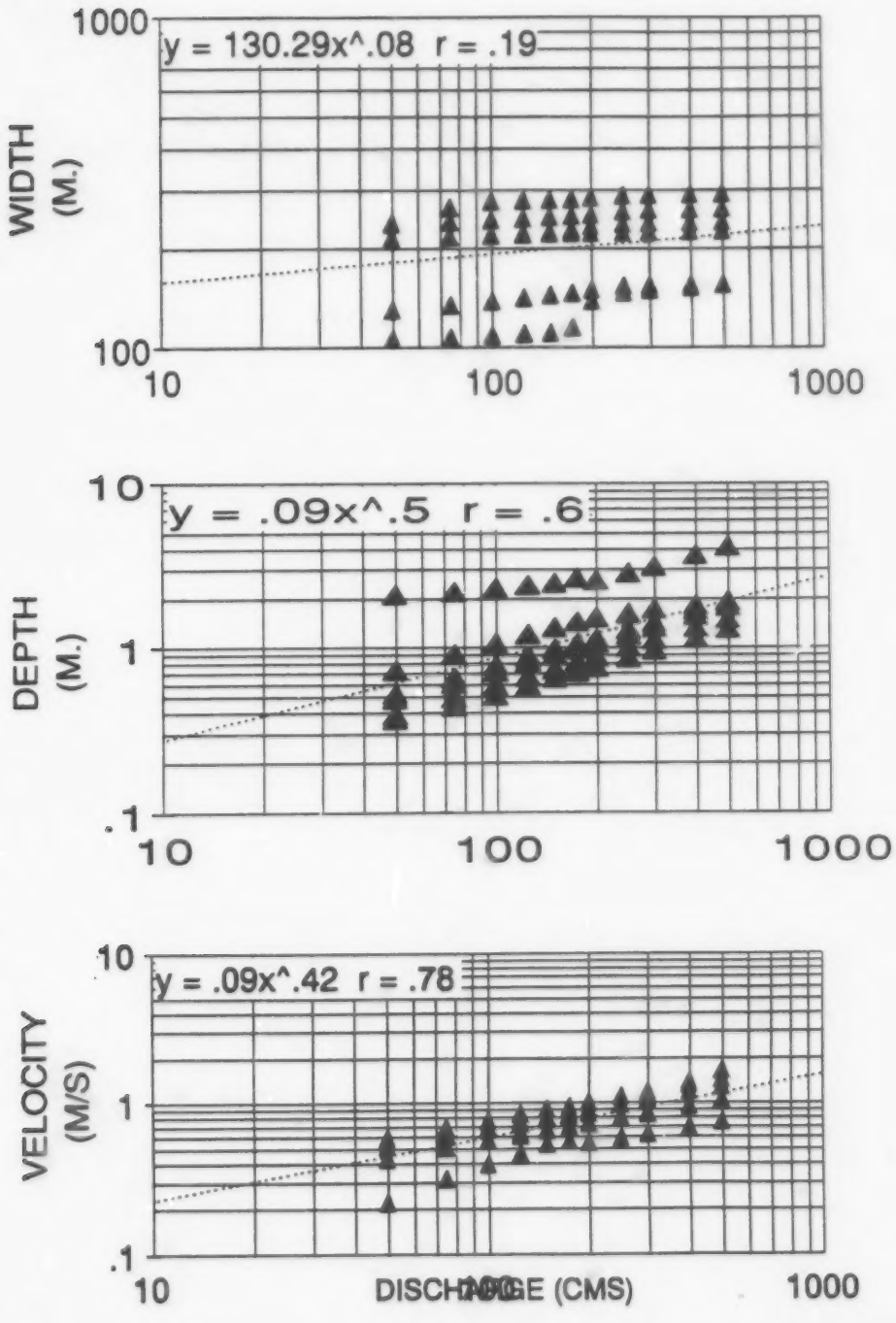


FIG. 9B

Regression Analysis Reach G
-Full Ice Cover-
Km. 262.0-287.5 (587.3-561.5)

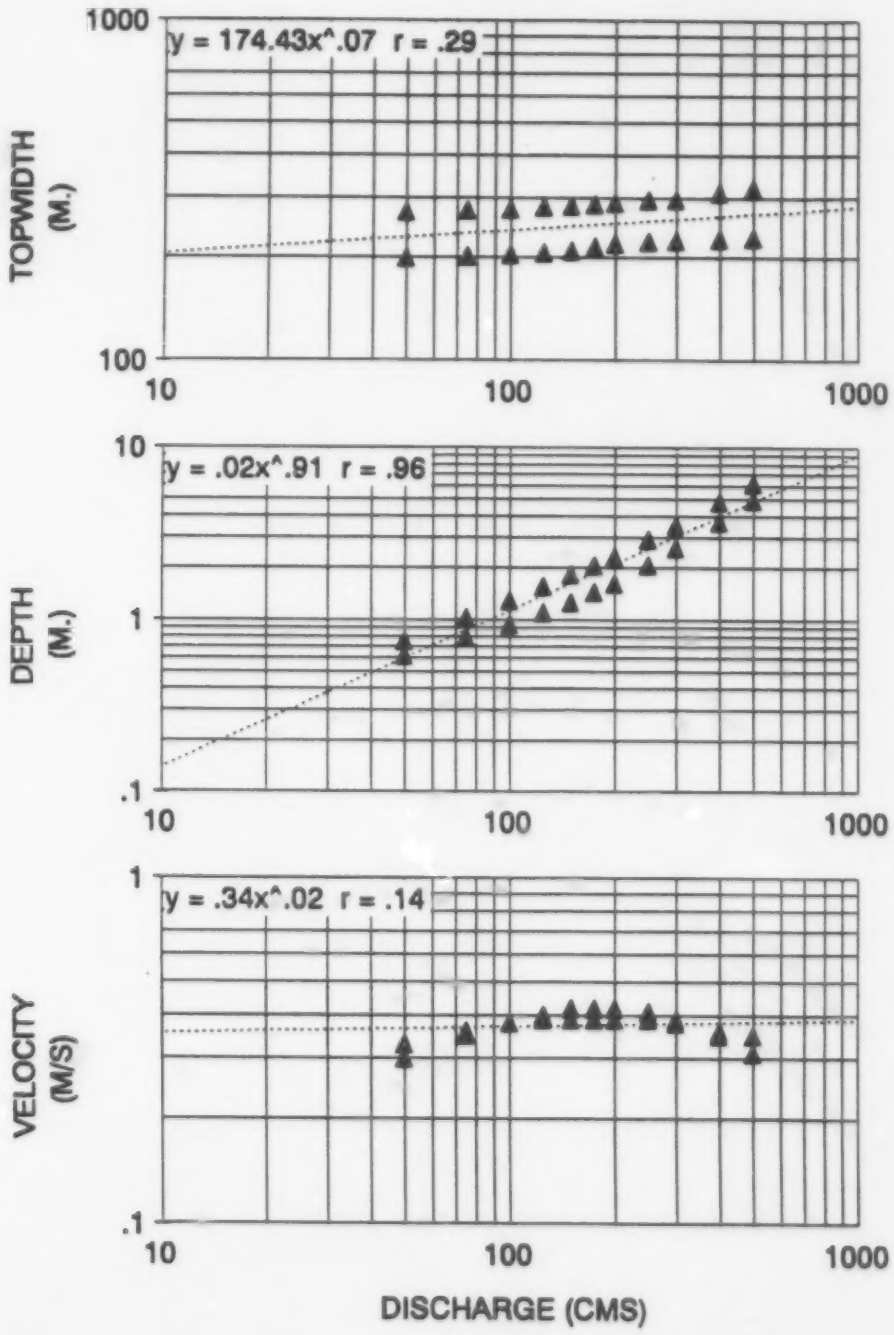


FIG. 10A

Regression Analysis Reach G
-Open Water-
Km. 262.0-287.5 (587.3-561.5)

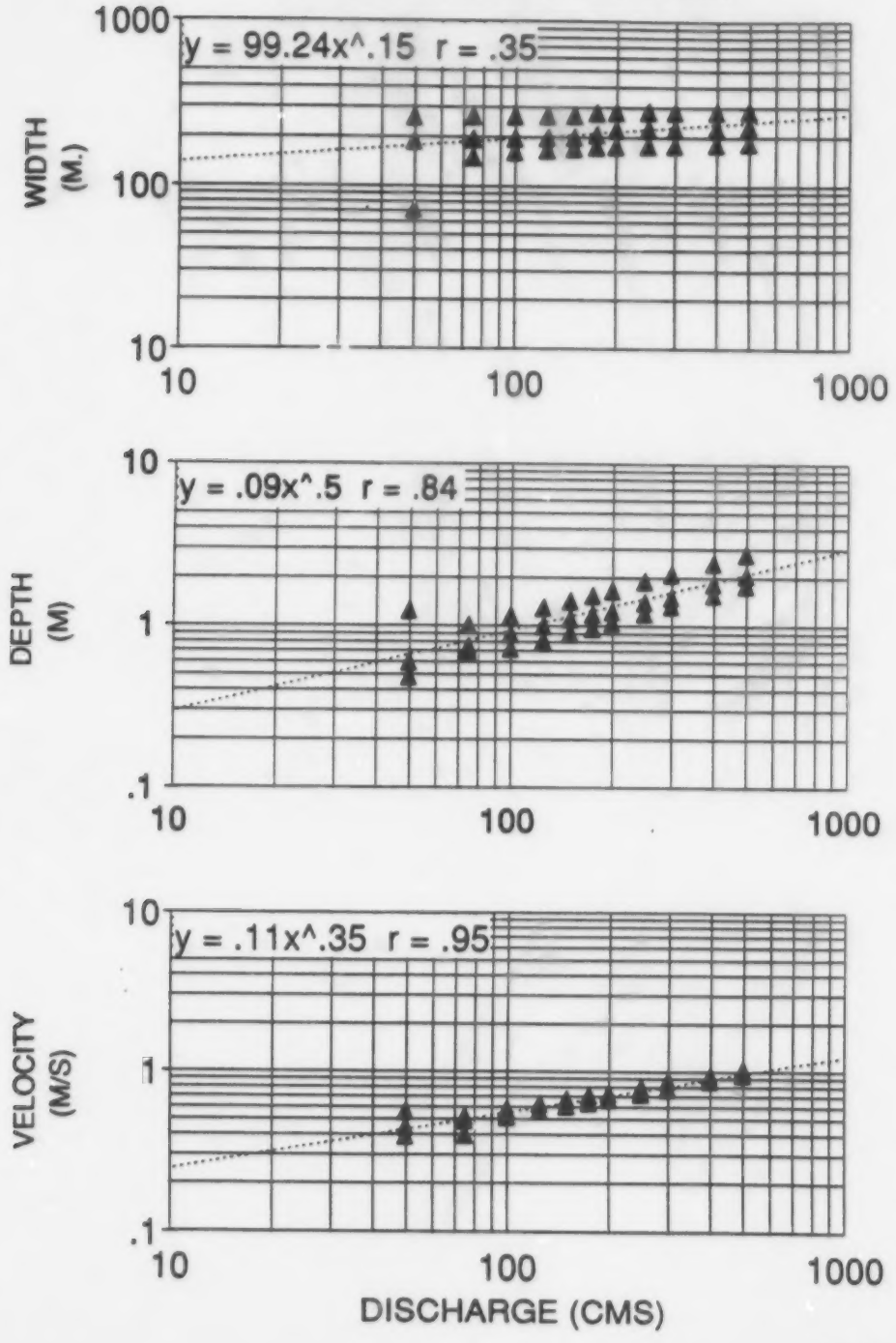


FIG. 10B

Regression Analysis Reach H
-Full Ice Cover-
Km. 287.5-326.2 (561.5-523.1)

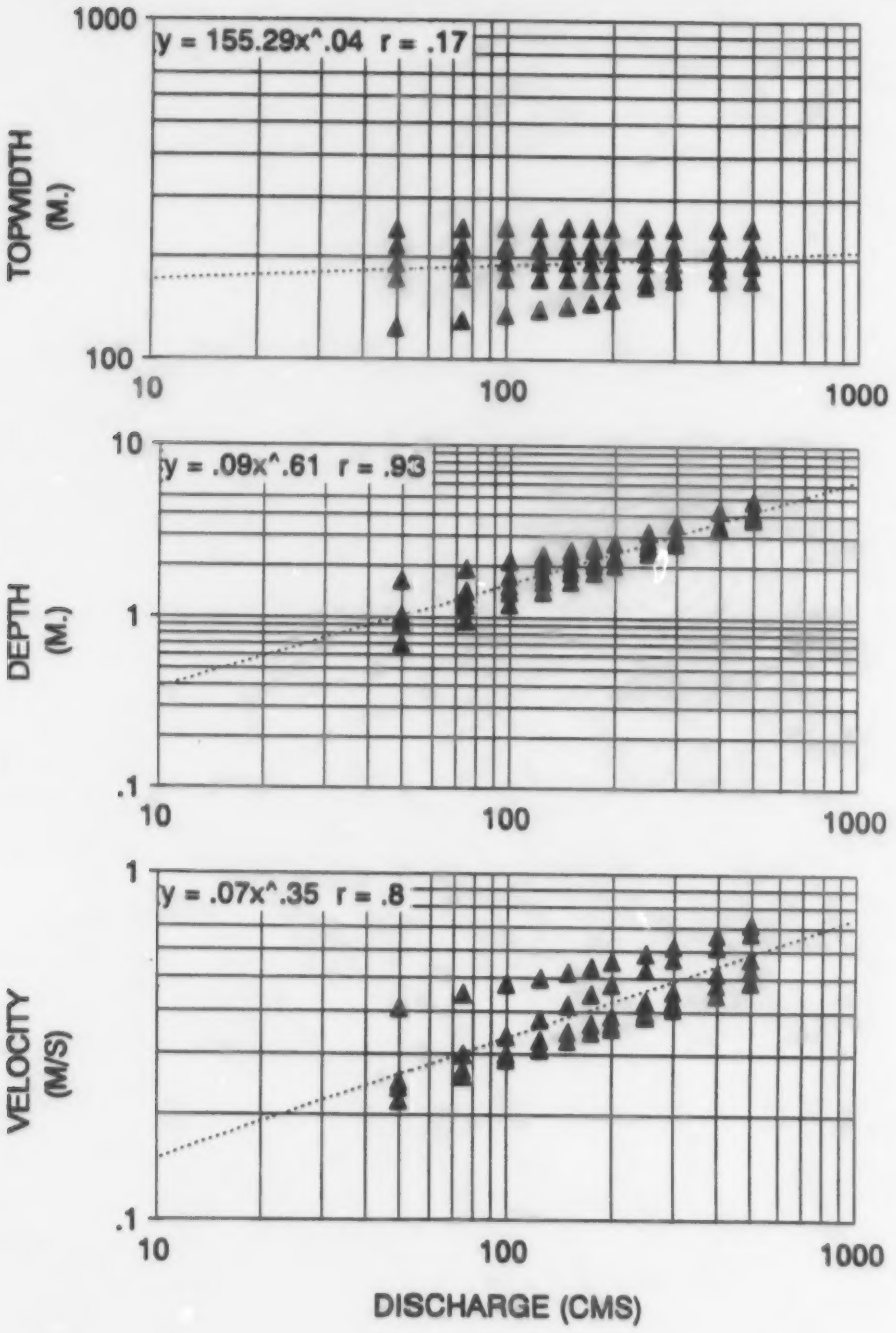


FIG. 11A

Regression Analysis Reach H
-Open Water-
Km. 287.5-326.2 (561.5-523.1)

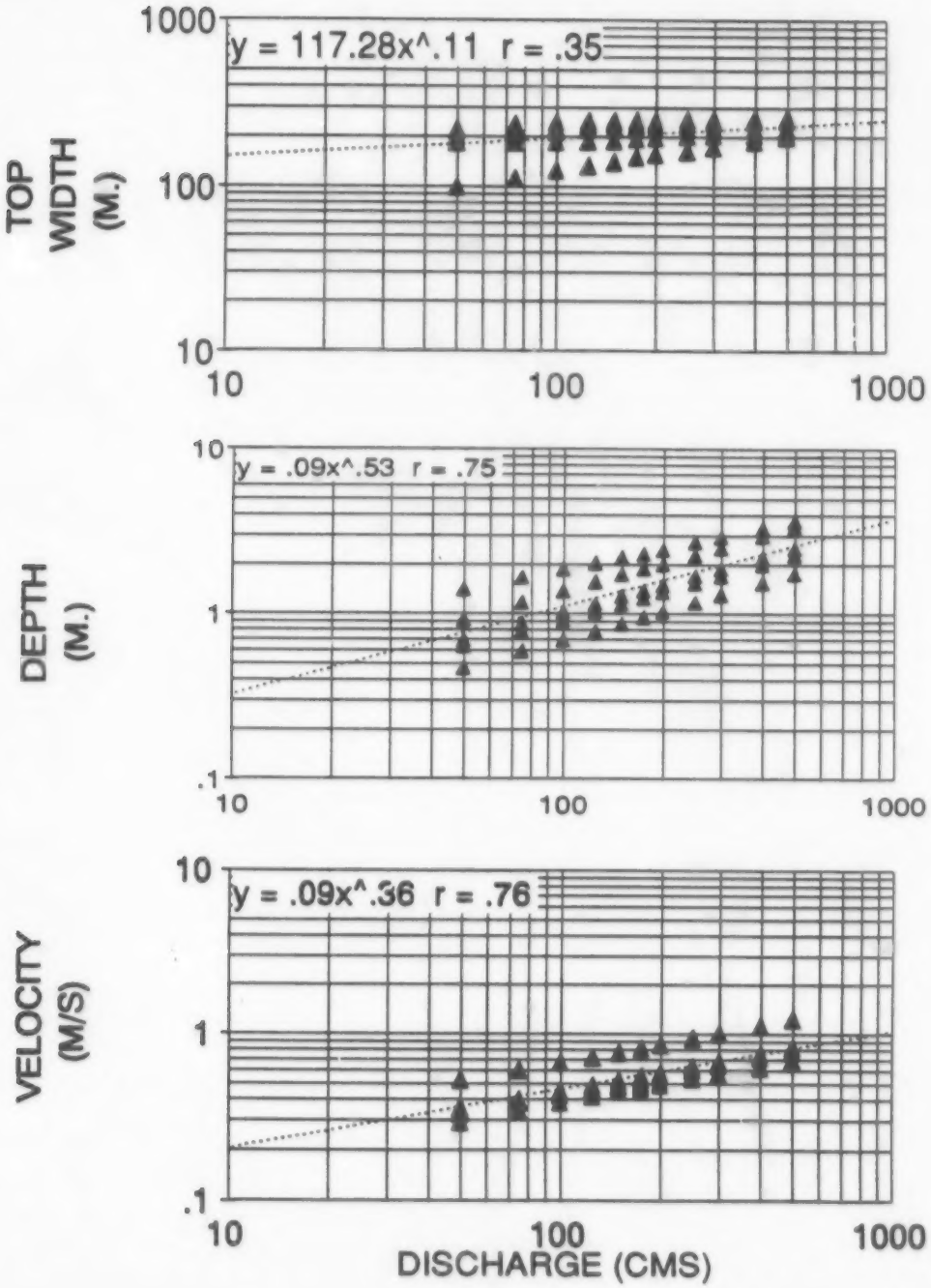


FIG. 11B

Regression Analysis Reach I
-Ice Cover-
Km. 326.2-355.2 (523.1-494.1)

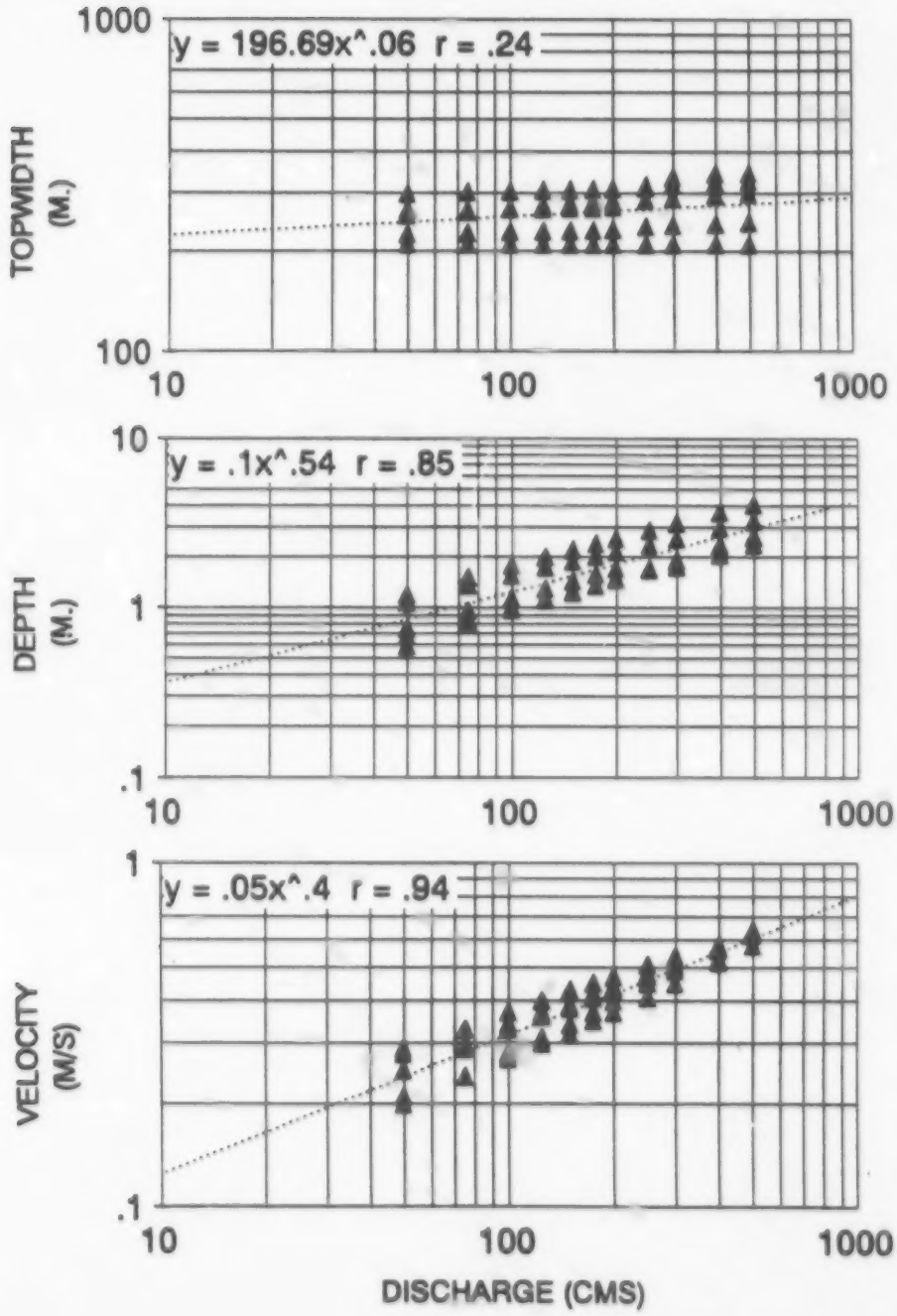


FIG. 12A

Regression Analysis Reach I
-Open Water-
Km. 326.2-355.2 (523.1-494.1)

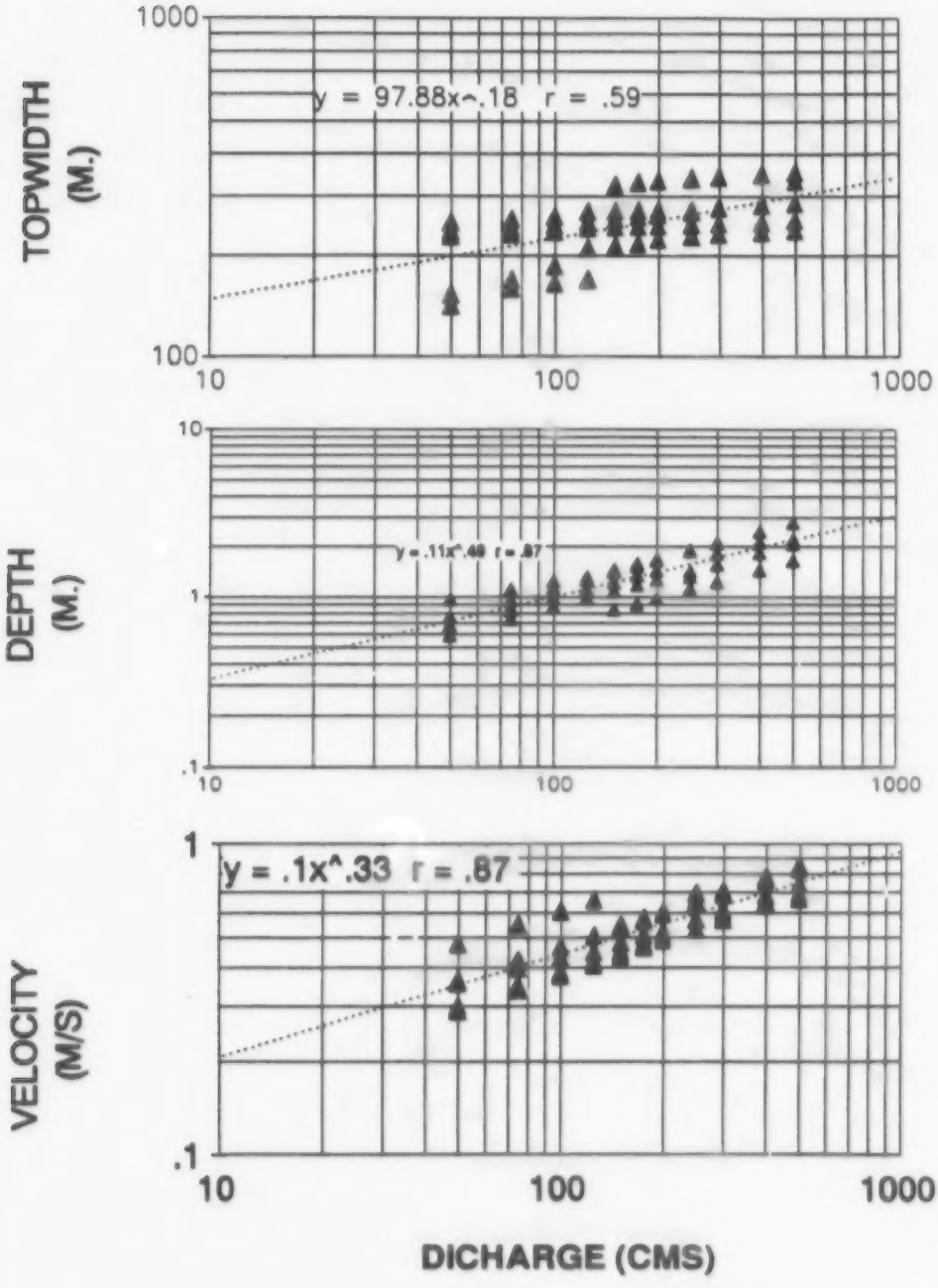


FIG. 12B